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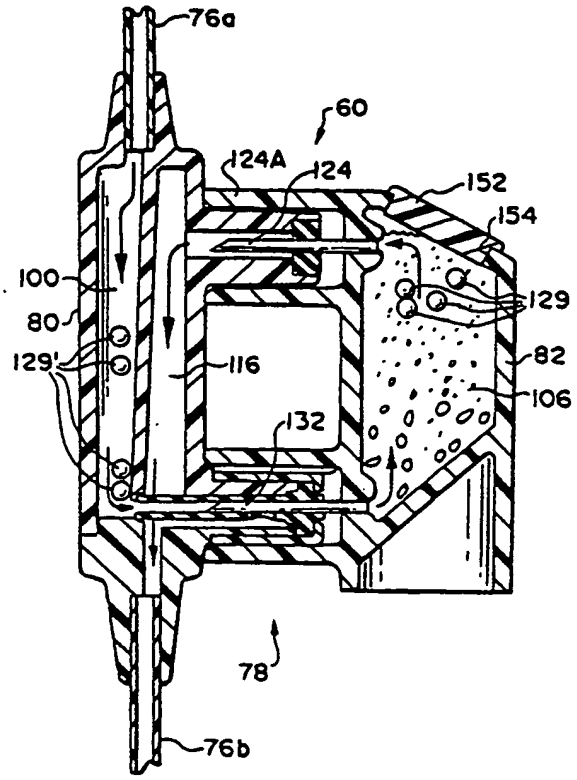
(54) Title: DRUG DELIVERY APPARATUS PREVENTING LOCAL AND SYSTEMIC TOXICITY

(57) Abstract

An apparatus (60) is provided for the safe, passive reconstitution of a drug or other beneficial agent, without requiring manual reconstitution steps. The apparatus (60) includes a housing (78), preferably having a receptacle (80) 'in-line' in an administration set and forming part of an intravenous delivery system, and cartridge (82) adapted for receiving a beneficial agent or beneficial agent and carrier. The cartridge (82) is plugged into the receptacle (80) to initiate reconstitution of the agent. The apparatus (60) creates first and second delivery modes, in which the delivery rate of the agent to a patient is independent from and dependent upon, respectively, the fluid flow rate through the intravenous delivery system.



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DRUG DELIVERY APPARATUS PREVENTING LOCAL AND SYSTEMIC TOXICITY

There is an application filed concurrently herewith, entitled "Housing Enabling Passive Mixing of a Beneficial Agent with a Diluent" filed in the name of Brian D. Zdeb et al., U.S. Patent Application Serial No. , assigned to the assignee of the present invention.

Technical Field of the Invention

The present invention is related to the delivery of a beneficial agent to a patient and is more particularly directed to the passive delivery of a drug to the intravenous system of a patient in a safe and effective manner.

Background of the Invention

Many drugs are mixed with a diluent before being delivered intravenously to a patient. The diluent may be, for example, a dextrose solution, a saline solution or even water. Many such drugs are supplied in powder form and packaged in glass vials or ampules. Other drugs, such as some used in chemotherapy, are packaged in glass vials or ampules in a liquid state.

Powdered drugs may be reconstituted in a well known manner, utilizing a syringe which is used to inject liquid into the vial for mixing, the syringe eventually withdrawing the mixed solution from the vial. When a drug must be diluted before delivery to a patient the drug is often injected into a container of diluent after it is

reconstituted, where the container may be connected to an administration set for delivery to a patient. More specifically, the diluent is often packaged in glass bottles, or flexible plastic containers such as are sold under the names MINI-BAG™ AND VIAFLEX® by Travenol Laboratories, Inc. of Deerfield, Illinois. These containers have administration ports for connection to an administration set which delivers the container contents from the container to the patient. The drug is typically added to the container through an injection site on the container.

Drugs may be packaged separately from the diluent for various reasons. One of the most important reasons is that many drugs do not retain their chemical and physical stability when mixed with a diluent and thus cannot be stored for any substantial period of time. Also, drugs are often packaged separately from the diluent because many firms which manufacture drugs are not engaged in the business of providing medical fluids in containers for intravenous delivery, and vice versa.

Therefore, a doctor, nurse, pharmacist or other medical personnel must mix the drug and diluent. This presents a number of problems. The reconstitution procedure is time consuming and requires aseptic technique. The operator must provide the proper diluent and a syringe before beginning. Often the powdered drug is "caked" at the bottom of the vial. Thus, when liquid is injected into the vial from a syringe the surface area of contact between the liquid and the powdered drug may be quite small initially, thus making the mixing procedure even more time consuming. Because of the limited vial volume, the increasing drug concentration in the diluent makes it harder to finish the reconstitution process. The operator may attempt to solve this by repeatedly injecting solution into the vial, mixing and withdrawing the solution but this makes necessary additional injections and movement of the syringe which increase the likelihood of contamination. Also, it is sometimes

difficult to get all of the drug and/or liquid out of the vial, thus increasing the time required to perform the reconstitution procedure.

The reconstitution procedure should be performed under preferably sterile conditions. In addition to such a requirement making the operator justifiably more cautious and consuming more time, sterile conditions are often hard to maintain. In some instances, a laminar flow hood may be required under which the reconstitution procedure is performed.

Some drugs, such as some chemotherapy drugs, are toxic. Exposure of the operator to the drugs during reconstitution may be dangerous, especially if the operator works with such drugs on a daily basis and is repeatedly exposed to them.

A further problem is that the reconstitution procedure provides a source of confusion as to which container contains which drug. The diluent container should be marked with the drug with which it has been injected and the name of the patient to whom it should be delivered.

After a drug is reconstituted and withdrawn into a syringe barrel, the drug may in some instances be injected immediately into the intravenous system of a patient. More typically however, the reconstituted drug is injected from the syringe into a larger container of solution as discussed above, for connection to an intravenous administration set. This is because often the drug reconstituted in the syringe is still at a concentration so high as to cause local toxicity in the veins of a patient near the injection site where the needle pierces the skin. This may create severe vein irritation which may be medically harmful. Additionally, while the proper dose of medication is in the syringe, immediate injection into the patient's blood stream may create a condition of systemic toxicity wherein the level of drug concentration in the patient's entire blood stream is dangerously high. Yet another reason for not

making the injection from the syringe directly into the patient is that it creates an additional injection site into the patient, which may be painful for the patient and provides another opportunity for infection.

For these reasons, the reconstituted drug is more typically injected into a diluent container.

A patient may typically be administered a dextrose or saline solution from a large volume parenteral container, for example, such as a one liter container, delivered through an administration set such as a CONTINU-FLO® administration set sold by Travenol Laboratories. If the reconstituted drug were injected into the large volume parenteral container, delivery of the drug would usually be delivered over too long a time period. Often, these large volume fluids are delivered at very slow flow rates.

More typically, the reconstituted drug is injected into a small volume parenteral container, such as a fifty milliliter container sold by Travenol Laboratories. This MINIBAG™ container is hung at a higher elevation than the large volume parenteral container and is connected by a secondary administration set to an injection site on the primary administration set. Because it is maintained at a higher elevation, the reconstituted drug in the small volume container is delivered, after which fluid from the large volume container begins to flow once more.

A closed reconstitution delivery system is disclosed in U.S. Patent Nos. 4,410,321; 4,411,662; 4,432,755; and 4,458,733, all assigned to Baxter Travenol Laboratories Inc., the assignee of the present invention. As shown therein, a container includes a drug and a diluent in separate compartments which are reconstituted in a closed system before the drug is delivered to the patient. Typically, the container is connected to an administration set which is connected at its other end to the primary administration set, such as with the small volume parenteral container described above.

The container shown in these patents solves many of the problems associated with syringe reconstitution. The product does however necessitate a series of reconstitution steps which must be performed by the nurse or other operator prior to delivering the fluid from the container.

Delivery of a drug or other beneficial agent in a manner not requiring reconstitution steps by an operator is shown in U.S. Patent Nos. 4,424,056; 4,432,756; 4,439,183; 4,474,574; 4,479,793; and 4,479,794 and Canadian Patent No. 1,173,795, assigned to Alza Corporation of Palo Alto, California. As disclosed in those patents, a parenteral delivery system is disclosed which has a formulation chamber therein for administering a beneficial agent such as a drug. The system is advantageous in that it provides for reconstitution of the drug by fluid flowing from a large volume parenteral container for example, through the administration set containing the formulation chamber with the drug therein. The system intends to eliminate the need for the time consuming reconstitution procedure described above and appears to eliminate the problems associated with the reconstitution procedure.

Another passive reconstitution system is disclosed in European Patent Application No. 0059694 to Aktiebolaget Hassle of Sweden.

Still another device for delivering a drug "in-line", i.e., in the administration set, is disclosed in Australian Patent No. 15762/83 and corresponding European Patent Application No. 0100296, assigned to Ciba Geigy AG of Switzerland. The device holds the drug and includes a section through which the liquid passes in a direction substantially opposite to the general direction in which liquid flows to the patient.

Yet another system which attempts to provide for drug reconstitution in-line without manual reconstitution by a nurse or other operator is shown in U.S. Patent No. 4,465,471, assigned to Eli Lilly and Co. of Indianapolis, Indiana. That patent discloses

constructions for a receptacle in the administration set itself. A separate cartridge containing the drug to be reconstituted and delivered to the patient is plugged into the receptacle. As liquid enters the cartridge for reconstitution of the drug and subsequent delivery out of the cartridge and receptacle and into the patient, some or most fluid continues to flow through the administration set, bypassing the cartridge entirely.

All the publications described above are directed to solutions to the time consuming reconstitution procedure and its associated problems. In most of the offered solutions, delivery of the drug is intended to be passive, i.e., once the drug is placed into the administration set, manual reconstitution steps are not required.

Still another common feature of the attempted solutions disclosed in these publications, except for U.S. Patent Nos. 4,410,321; 4,411,662; 4,432,755; and 4,458,733 is that delivery of the drug is intended to be able to be made in a manner which is essentially independent of the fluid flow rate through the administration set and into the patient. Stated differently, the systems are designed to deliver a certain dosage of drug in a preselected time period, within a broad range of fluid flow rates. Delivery of a drug independent of flow rate is desirable because it ensures that the necessary dosage will be delivered within a therapeutically acceptable time period, which may be typically about twenty to thirty minutes, although this time period may vary depending upon the drug and dosage.

By making delivery of the drug or other beneficial agent independent of the flow rate, the system ensures that the drug will not be delivered too quickly should the flow rate be set too high by the nurse or other operator, thereby preventing the problem of systemic toxicity discussed above.

Some of the documents, such as U.S. Patent Nos. 4,424,056; 4,479,793; and 4,479,794, are also directed to systems having a beneficial agent placed "in-line" in an administration set for mixing of the agent and delivery to a patient, wherein the delivery of the agent may be made in a given volume of fluid. Also, a valve controlling fluid flow may be manually operated to deliver the agent in a manner which can be made dependent upon fluid flow.

It is believed that all of the automatic reconstitution type systems suffer from a critical disadvantage which does not take into account typical conditions in a hospital setting. The critical disadvantage is that at low flow rates, there is a danger that the concentration of drug in the fluid being delivered to the patient will become dangerously high, resulting in local toxicity to the patient near the point of introduction into the body.

Nurses typically work with heavy work loads and need to react quickly to emergency situations. It is possible that a nurse setting up one of the passive type delivery systems mentioned above would need to leave the patient to respond to an emergency elsewhere. The nurse may attempt to keep the "status quo" by turning off fluid flow or turning it very low before rushing away from the patient's bed side. Alternatively, the nurse may forget to set an adequately high flow rate. Yet another possibility is that the flow rate may decrease over time as the fluid is being delivered to the patient because of, for example, changes in the administration set tubing lumen as restricted by a controller such as a roller clamp, over time, or changes to the system caused by movement of the patient or the delivery system or both.

It is believed that the possibility of a situation existing with a low flow rate in a passive type drug reconstitution system is significant. It is further believed that the resulting harm to the patient may be severe.

Another disadvantage of some of the passive type drug delivery systems is that they require the chamber or housing for the drug or other beneficial agent to be incorporated into the administration set so that the drug must be sold as a unit with the administration set. Such an arrangement is medically impractical and commercially unfeasible because it necessitates that a hospital keep a large inventory of sets, according to type of drug and dosage. The hospital purchase agent must anticipate usage of various types of drugs in addition to anticipating usage of various types of administration sets. Furthermore, such an arrangement necessitates changing the set every time it is desired to deliver a dose of a beneficial agent, greatly raising hospital costs for sets, requiring significant additional nursing time, increasing the chances of infection and disturbing the patient. For example, if four doses were required per day, four different administration sets would be required, whereas a typical administration set might be used for twenty-four to perhaps forty-eight hours. Such an arrangement also raises difficult problems of keeping the drug in an environment separate from moisture and air during storage, which may have a deleterious effect on drug efficacy.

Known cartridge type systems may solve the problems associated with an in-line drug system, but may suffer from the need for temporarily disconnecting the administration set delivering the drug to incorporate the housing having the drug therein within the delivery system.

Existing cartridge type device designs may suffer from other drawbacks, such as the need for an air eliminating device within the cartridge to permit the device to operate, thereby raising the cost of the cartridge; the need for a liquid-pervious barrier to the dry medicine in the cartridge; or the existence of flow patterns which do not appear to effectuate the efficient delivery of a large percentage of the drug dosage in the required time period.

Existing cartridge device designs do not direct all fluid flow through the cartridge, which results in a more complicated delivery system that is harder to control with different drugs and may require more than one receptacle configuration depending on the kind of drug in the inserted cartridge.

Existing cartridge device designs do not provide for fluid flow around all the beneficial agent in the cartridge from the beginning of fluid flow therethrough, resulting in inconsistent mixing over time.

Existing cartridge device designs do not include means for preventing insertion of the cartridge into the receptacle in an improper manner and do not include any visual indicator that the drug dose has been mixed and delivered downstream.

Summary of the Invention

The present invention solves the medically unacceptable problem of excessively high drug concentrations near the entry point into a patient's intravenous system at low fluid flow rates with a passive reconstitution type drug delivery system. The apparatus of the present invention recognizes and includes the advantages of a passive drug delivery system which eliminates the time consuming manual reconstitution procedure and the problems associated with manual reconstitution.

The apparatus of the present invention recognizes and includes the advantages of a passive system for delivery of a beneficial agent at a rate which is substantially independent of fluid flow rate.

The apparatus of the present invention effectively eliminates the problem of dangerously high delivery concentration, or local toxicity, which is associated with known passive type drug delivery systems directed to the delivery of a beneficial agent in a manner essentially independent of the flow rate.

The present invention is directed to an apparatus which provides for passive reconstitution of a beneficial agent while effectively preventing both systemic and local toxicity.

The apparatus of the present invention provides for the passive reconstitution of a beneficial agent and delivery of a therapeutically beneficial dose of the agent to a patient in a therapeutically acceptable time period.

The apparatus of the present invention permits delivery of a therapeutically beneficial dose of a beneficial agent within a time period of roughly twenty to thirty minutes, where required.

The invention is further directed to an apparatus that enables the safe delivery of a selected portion of the available beneficial agent in a given volume of fluid, even if fluid flow has been previously stopped. Another selected portion of the available beneficial agent may even be delivered subsequently, if desired, thereby enabling "multiple-dosing".

The apparatus of the present invention maintains the above-described advantages while solving the dangerous situation which occurs with other passive type systems at low flow rates, by including a housing which defines a chamber adapted for receiving a beneficial agent. A fluid pathway extends through the housing. The chamber may reach the hospital with the beneficial agent already therein, or the housing may be designed so as to permit addition of a beneficial agent to the housing by hospital personnel.

The apparatus of the invention further includes means for controlling the rate of delivery of the beneficial agent out of the housing outlet. The control means is capable of producing first and second delivery modes for the beneficial agent, depending upon the flow rate of fluid through the outlet. In the first delivery mode, at fluid flow rates at or above a preselected flow rate transition region, the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through the chamber, thereby both (1) enabling delivery of a therapeutically beneficial dose quickly enough to be within a therapeutically acceptable time period and (2) preventing systemic toxicity of the drug in the patient's blood stream. Systemic toxicity is prevented because the delivery rate of the agent has an upper limit, which prevents a "runaway" system where too much agent would otherwise be in the patient's bloodstream because of a high flow rate.

In the second delivery mode at or below a fluid flow rate transition region preselected by the control means, the rate of delivery of the beneficial agent is at least partially dependent upon the fluid flow rate through the chamber. Thus, at fluid flow rates at or below the preselected fluid flow rate transition region, the second delivery mode prevents local toxicity of the beneficial agent to the patient.

Even more important than providing an apparatus with control means creating both first and second delivery modes, the present invention is directed to an apparatus having control means that can

control the flow rate range of the second delivery mode and wherein the fluid flow rate transition region between the first and second delivery modes is at a preselected range of fluid flow rates high enough to prevent toxic concentration of beneficial agent in the fluid delivered to the patient (local toxicity).

The housing may further include a carrier for the beneficial agent, within the chamber. The carrier may be part of the control means and may be any of a number of structures to provide for release of the agent therefrom. As an example only, the carrier may be a dissolvable substance such as mannitol. The carrier may be a nondissolving material such as polypropylene. The carrier and beneficial agent may be in the form of a single tablet, smaller pellets, or powder for example. The carrier may be in a different form, such as a membrane coating agent particles.

The control means for defining the fluid flow rate transition region includes one or more structural features in order to convert delivery of the beneficial agent from a mode of fluid flow rate independence, i.e., a constant weight of agent delivered per unit of time, to a mode of fluid flow rate dependence, i.e., a relatively constant weight of agent delivered per fluid volume unit. This critical delivery mode determining structure may include the cross-sectional area of the fluid pathway in the apparatus, the local velocity profile of fluid passing over the beneficial agent, the thickness of the diffusional boundary layer of fluid passing over the beneficial agent or a plurality of non-series connecting fluid pathway segments which form the fluid pathway in the housing, in which at least one fluid pathway segment is exclusive of flow-path communication with the beneficial agent, for example.

The control means may further include the percentage of void volume of the beneficial agent or carrier, the rate of dissolution of the beneficial agent or carrier, the particle size of the

beneficial agent or carrier, the surface area of the beneficial agent or carrier in contact with fluid flowing through the fluid pathway or the shape of the beneficial agent or carrier within the chamber.

The control means may further include the weight ratio of the beneficial agent to a carrier for the agent, the percentage of void volume of the carrier as measured with or without the beneficial agent therein, the rate of dissolution of a dissolvable carrier and agent, the amount of surface area of the carrier with the beneficial agent therein in contact with fluid flowing through the fluid pathway, the shape of the carrier with the beneficial agent therein, or the thickness of the diffusional boundary layer of fluid passing over the carrier or over the combined carrier and agent.

The present invention is also directed to a method for the passive mixing of a beneficial agent with a diluent and delivery of the agent to a patient while preventing both local and systemic toxicity.

Description of the Drawings

FIG. 1 is a plan view of an intravenous delivery system including a fluid source and a fluid conduit, including the apparatus of the present invention;

FIG. 2 is a plan view of a prior art drug delivery system, utilizing large and small volume parenteral solution containers maintained at different elevations;

FIG. 3 is a cross-sectional view of a housing, including a receptacle "in-line" in an administration set and a separate cartridge adapted for receiving a beneficial agent;

FIG. 4 is a cross-sectional view of the housing illustrated in FIG. 3, but illustrating the cartridge as secured to the receptacle;

FIG. 5 is a graph tracking time of release of a beneficial agent as a function of fluid flow rate with certain control means, illustrating the fluid flow rate transition region and the first and second delivery modes;

FIG. 6 is a cross-sectional view illustrating an alternate housing, used to generate the data shown in FIG. 5;

FIG. 7 is a schematic view of a porous polypropylene particle such as used to make the tablet in the housing of FIG. 6;

FIG. 8 is a schematic, fragmentary enlarged view of the tablet shown in the housing of FIG. 6, illustrating both the beneficial agent and the polypropylene carrier;

FIG. 9 is a schematic, fragmentary enlarged view of the tablet in the housing of FIG. 6, illustrating channels of beneficial agent within the polypropylene carrier;

FIG. 10 is a schematic, cross-sectional view illustrating local velocity profiles and a diffusional boundary layers;

FIG. 11 is a cross-sectional view of a housing with pellets therein;

FIG. 12 is a cross-sectional view of a housing having powder therein;

FIG. 13 is a cross-sectional view of a housing having a tablet therein including a beneficial agent and a dissolvable carrier;

FIG. 14 is a schematic, cross-sectional view illustrating a split fluid pathway with parallel flow segments, with a beneficial agent in one of these fluid segments;

FIG. 15 is a cross-sectional view of a housing similar to the housing illustrated in FIGS. 3 and 4, but without the flow director, and with split-flow, parallel flow segments;

FIG. 16 is a perspective view of another housing;

FIG. 17 is a cross-sectional view of the housing illustrated in FIG. 16;

FIG. 18 is a cross-sectional view of still another housing, including an "in-line" receptacle, a separate intermediate portion and a separate cartridge adapted for receiving a beneficial agent; and

FIG. 19 is a cross-sectional view of the housing illustrated in FIG. 18, but with the intermediate portion of the receptacle secured to both the "in-line" portion of the receptacle and the cartridge.

Detailed Description of Examples Embodying the Best Mode of the Invention

Referring to FIG. 2, there is disclosed a prior art intravenous delivery system 20 including a first fluid source such as a first fluid container 22 having a liquid therein such as water, a dextrose solution or saline solution for example. A first administration set 24 is connected by a first set spike connector 26 at its proximal end to a first container administration port 28 on the first container 22, and by a first set Luer connector 30 to a catheter 31 which enters the patient's intravenous system through the skin.

The first administration set 24 includes a check valve 32, a first flow regulating means such as a first set roller clamp 34 and a "Y" adapter injection site 36. The prior art intravenous delivery system 20 further includes a second fluid source such as a second fluid container 38 which contains a diluent such as sterile water, dextrose, or saline solution for example. A reconstituted drug may be injected into the second fluid container 38 by means of the second container injection site 40.

A second administration set 42 is connected by means of a second set spike connector 44 at its proximal end to the second container administration port 46, and by a needle 48 at its distal end to the first administration set 24 through the "Y" adapter injection site 36. The second administration set 42 includes a second flow regulating means such as a second set roller clamp 50. Each of the first and second administration sets 24, 42 includes a drip chamber 52, 54 respectively by which fluid flow through the sets 24, 42 may be determined by counting drops entering the drip chambers.

The first and second fluid containers 22, 38 may be hung by metal hangers 56 from an IV equipment pole (not shown). The second fluid container 38 is hung at a higher elevation than the first fluid container 22 so that the drug and diluent in the second container 38 will interrupt delivery of fluid in the first container 22 because of a higher head pressure. After the fluid in the second container 38 is delivered, delivery of fluid from the first container 22 to the patient resumes.

In contrast, there is shown in FIG. 1 an intravenous delivery system 58 including an apparatus 60. A fluid source such as a container 62 contains a fluid, such as sterile water, dextrose solution or saline solution for example, to be delivered to the patient. The container 62 includes an injection site 64 and an administration port 66. A fluid conduit including an administration set 68 includes a spike connector 70 at its proximal end for piercing a membrane in the administration port 66 to permit fluid to flow from the container 62 to the set 68. Downstream of the spike connector 70 is a drip chamber 72 by which a nurse or other operator may count drops per unit of time to determine the fluid flow rate through the delivery system 58. A flow regulating device such as a roller clamp 74 is disposed about plastic tubing 76 downstream of the drip chamber 72. The apparatus 60 is disposed "in-line" in the fluid conduit.

The apparatus 60 includes a housing 78. It is preferred that the housing include a receptacle 80 which is disposed in the fluid conduit tubing 76 and a separate, plug-in cartridge 82. Downstream of the housing 78 is a fluid filter 84 which may be, for example, a hollow fiber filter. The fluid filter 84 includes air eliminating means such as an air eliminating membrane 86 for eliminating air entrained in the fluid conduit. Air entrained in the fluid conduit exits the conduit into the environment through the air eliminating membrane 86.

The distal end of the administration set 68 includes a male Luer adapter 69 which connects to a catheter hub 90 of a catheter 92, which enters the patient's intravenous system through the skin.

Many other configurations of the administration set 68 for use with the apparatus 60 are possible. For example, the flow regulating means may be a separate pump into which the tubing 76 is mounted, eliminating the need for the roller clamp 74.

In this disclosure the housings and apparatus are discussed with reference to intravenous delivery systems and the intravenous system of a patient. However, the housings and apparatus may be used for the introduction of a beneficial agent into a patient at locations other than the patient's intravenous system. "Intravenous" is meant to include those other locations. The apparatus and housings are adapted for receiving a beneficial agent. "Beneficial agent" is meant to include diagnostic substances as well as substances intended to have a medically beneficial effect.

Referring now to FIGS. 3 and 4, there is illustrated the apparatus 60. The apparatus 60 includes a housing 78 which includes a receptacle 80 including an inlet 94 connected to an upstream portion 76a of the fluid conduit and an outlet 96 connected to a downstream portion 76b of the fluid conduit. The housing 78 includes a separate cartridge 82 which is plugged into the receptacle 80 to form the complete housing 78. The housing 78 may also be constructed so that the cartridge 82 and the receptacle 80 are made as a unit.

The housing 78 defines a fluid pathway 98 therethrough. The inlet 94 and the outlet 96 define part of the fluid pathway 98. The fluid pathway forms part of the fluid conduit of the intravenous delivery system 58.

The housing includes a fluid receiving segment 100 having an upstream end 102 in fluid communication with the inlet 94, and a downstream end 104. A chamber 106 adapted for receiving a

beneficial agent 108 and a carrier 110 is defined by the cartridge 82. The chamber 106 defines part of the fluid pathway 98 in the housing 78. As shown in FIGS. 3 and 4, the agent and carrier are in pellet form, but other forms are also possible, as discussed below.

The chamber includes an upstream end 112 adapted for fluid communication with the receiving segment downstream end 104. The chamber also includes a chamber downstream end 114.

The housing 78 further defines a discharge segment 116 of the fluid pathway 98, including a discharge segment upstream end 118 adapted for fluid communication with the chamber downstream end 114, and a discharge segment downstream end 120 in fluid communication with the outlet 96.

The housing 78 further includes connecting means in both the receptacle 80 and the cartridge 82 for securing the cartridge to the receptacle and providing for fluid flow therebetween. The connecting means includes first and second cross-over segments 122, 124. The first cross-over segment 122 is disposed between and adapted for providing fluid communication between the receiving segment downstream end 104 and the chamber upstream end 112.

The second cross-over segment 124 is disposed between and adapted for fluid communication between the chamber downstream end 114 and the discharge segment upstream end 118. The first and second cross-over segments 122, 124 are each disposed in both the receptacle 80 and the cartridge 82.

Puncturable means are disposed in and block both the first and second cross-over segments 122, 124 in the housing 78. The puncturable means used in the housing 78 are resilient, rubber-like injection sites 126, 128 disposed in the first and second cross-over segments 122, 124 respectively. The injection sites are mounted at the ends of the receptacle portions of the first and second cross-over segments and form part of the connecting means between the cartridge and receptacle.

Puncturing means are provided in both the first and second cross-over segments 122, 124 for puncturing the puncturable means. In the housing 78, the puncturing means comprise pointed, hollow cannulas 130, 132 mounted in the cartridge portion of the first and second cross-over segments 122, 124 respectively. The cannulas 130, 132 form part of the connecting means. When the cartridge and receptacle are urged together, the cannulas 130, 132 pierce the injection sites 126, 128 respectively, thereby placing the receiving segment 100, the chamber 106 and the discharge segment 116 in fluid communication.

The first cross-over segment injection site 126 is part of a flow director 134 which is a puncturable means. In addition to the injection site 126, the flow director 134 includes a tube 136 having an upstream end 138 fluid-sealingly connected to the receiving segment downstream end 104. The injection site 126 closes the opposite end 140 of the tube 136. It is preferred that the flow director 134, including the tube 136 and the injection site 126 be made as a single piece.

The flow director 134 defines a flow bypass opening 142 in the wall of the tube 136. It is preferred that the tube 136 is resilient and sized so as to seal about the outer periphery of the cannula 130 which pierces the injection site 126, as illustrated in FIG. 4. The flow director 134 intersects but does not occlude the discharge segment 116.

Referring to FIG. 3, when the cartridge 82 is not plugged into the receptacle 80, fluid flowing from the fluid source through the fluid conduit 76 flows from the conduit upstream portion 76a, through the inlet 94 and into the receiving segment 100 of the fluid pathway 98. The fluid flows out the receiving segment downstream end 104, into the flow director 134, and then out of the flow director 134 through the flow bypass opening 142, whereupon it continues to flow out the outlet 96 into the downstream portion 76b of the plastic tubing 76.

Referring now to FIG. 4, when the chamber is in fluid communication with the receiving segment and the discharge segment, the tube 136 seals around the outer periphery of the cannula 130 so that fluid entering the flow director 134 does not exit through the flow bypass opening 142. Instead, fluid entering the flow director 134 flows through the cannula 130 into the chamber 106. The fluid continues to flow through the cannula 132, into the discharge segment 116. Fluid in the discharge 116 flows around the flow director 134, into the outlet 96 and the downstream portion 76b of the conduit. It will be seen from FIG. 4 that the direction of fluid flow through at least a portion of the chamber is in a direction generally opposite to the direction of fluid flow from the fluid source to the patient. In the housing 78, fluid flow through the chamber 106 is in a generally upward direction, which is generally opposite to the downward direction of fluid flow from the container 62 to the patient.

As fluid flows through the chamber 106, the beneficial agent 108 in the chamber 106 mixes with the fluid and is subsequently delivered therewith to the patient. As will be explained below, the beneficial agent 108 may be placed in the chamber 106 alone or combined with a dissolvable or nondissolvable carrier material 110. The beneficial agent 108 or the combined beneficial agent and carrier 108, 110 may be in pellet form as illustrated in FIGS. 3 and 4 or in a larger tablet form or in powder form with very small separate particles.

It has been found that the housing 78 permits passive drug delivery. The nurse, pharmacist or other operator need not go through a series of manual reconstitution steps. Once the cartridge 82 is plugged into the receptacle 80 and fluid begins to flow, the drug or other beneficial agent 108 is automatically mixed in with the fluid for delivery to the patient.

The upward flowpath in the chamber 106 of the housing 76 is important. Because the downstream or discharge end 114 of the chamber 106 is at the top of the chamber 106, the fluid at the downstream end 114 of the chamber has a concentration of beneficial agent 108 lower than if the downstream end of the chamber were at a lower elevation than the upstream end of the chamber. This assists in creating a housing 78 which permits delivery of the beneficial agent 108 in a manner substantially independent of the fluid flow rate so that the amount of beneficial agent 108 delivered per unit time period is substantially a constant for a given housing and beneficial agent.

Thus, the housing 78 allows for delivery of the beneficial agent 108 in a time period short enough to be therapeutically effective, such as between twenty and forty minutes. This time period is not intended to be a limitation but does represent a typically desirable delivery period for many intravenously delivered drugs. The housing 78 also prevents the drug from being delivered too quickly at high flow rates so that the medically unacceptable condition of systemic toxicity discussed above will not occur. Stated differently, the housing 78 prevents the patient's blood stream from having a dangerously high concentration of beneficial agent 108.

The upward flowpath in the chamber 106 also aids in mixing by creating swirling of the fluid as it flows upwardly through and around the beneficial agent 108. The upward flow path also assists in forcing downstream out the outlet 96 the air entrained in the housing and in the system upstream of the housing. This permits easy priming of the housing with the cartridge therein. In fact, the cartridge 82 is self-priming. Furthermore, the upward flow path in the chamber 82 of the housing 78 eliminates the need for an air vent or other air eliminating means in the cartridge 82 itself.

It is believed that air eliminating means should be included in the fluid conduit of the intravenous delivery system 58. As shown in FIG. 1, the air eliminating means may simply be the air eliminating membrane 86 of a commercially available fluid filter 84. The air eliminating means eliminates air entrained in the fluid conduit, including the housing. Although it is possible for the air eliminating membrane to be disposed within the housing, it is preferable that it be disposed downstream of the housing. By so doing, the system 58 takes advantage of the air eliminating membrane 86 already in the known fluid filter 84 which would probably be desirable in the system even without the housing. By permitting the air eliminating membrane to be external of the housing 78, and particularly external of the cartridge 82 with the chamber 106 therein, the manufacturing costs of the housing and particularly the cartridge 82 are significantly reduced.

Preferably, the chamber upstream portion adjacent the chamber upstream end 112 has a funnel-like configuration, such as the sloping upstream chamber wall 148. As seen in FIGS. 3 and 4, the funnel-like shape widens in the downstream direction. This configuration aids in the mixing process and helps to direct fluid flow around all of the beneficial agent 108, from the beginning of fluid flow through the chamber. Also preferable is a funnel like configuration adjacent the chamber downstream end 114, such as the sloping, downstream chamber wall 150 that creates a substantially funnel shape which narrows in the downstream direction. Such a structure assists in aiding fluid flow out of the chamber 106.

An additional feature of the housing 78 is a chamber plug 152 sealing a chamber access port 154. The beneficial agent 108 may be placed into the chamber 106 through the chamber access port 154. This design permits manufacture of the housing 78 with the beneficial agent 108 therein, or manufacture of a cartridge 82 which may be delivered to the hospital without a beneficial agent therein. The hospital pharmacist or the operator may then simply take out the plug, insert the beneficial agent 108 and reseal the chamber plug 152 in the access port 154, under aseptic conditions. The chamber plug 152 may be a resilient, puncturable, resealable material, to enable filling the chamber with a syringe and needle through the plug 152 in those cases where the beneficial agent is added to the cartridge 82 in the liquid state.

If the cartridge 82 is manufactured with the beneficial agent therein, the plug 152 may be sealed by means of an ultrasonic weld, solvent bonding or other permanent means. If the cartridge 82 is manufactured for addition of a beneficial agent 108 by hospital personnel, the plug 152 may be designed with a tight friction fit preventing contamination of the chamber through the access port 154 after the chamber has been resealed by the pharmacist.

Preferably, the cartridge 82 includes protective sleeves 156, 158 disposed around and spaced from the cannulas 130, 132 respectively, preventing touch contamination. The sleeves 156, 158 may be covered by removable foil tabs 160, 162 respectively, adhesively secured to the sleeves 156, 158. The tabs 160, 162 are removed before the cartridge 82 is inserted into the receptacle 80.

The protective sleeves 156, 158 also serve the important function of properly aligning the cannulas 130, 132 within the injection sites 126, 128. This is especially important for proper insertion in the flow director 134. The sleeves 156, 158 may have an inner diameter of for example about 0.005 to 0.020 inch greater than the outer diameter of the portions 122A, 124A of the first and

second cross-over segments respectively on the receptacle 80. Thus, when the cartridge is plugged into the receptacle the cannula 130 will be centered in the injection site 126 so that the cannula 130 enters the inside of the tube 136 in the flow director.

An additional feature of the cartridge 82 is key way means to prevent the cartridge 82 from being secured to receptacle 80 upside down. The key way means includes a key 164 which, as illustrated in FIG. 3, is mounted on the internal wall of the sleeve 156. The key fits into a slot 166 on the portion 122A of the first cross-over segment 122 on the receptacle 80. The key way means could include many other configurations and may be disposed on the second cross-over segment 124 as well as or instead of the first cross-over segment 122. The key way means prevents the second cannula 132 from piercing the one injection site 126 and prevents the first cannula 130 from piercing the other injection site 128.

Preferably, at least a portion of the cartridge 82 is optically transparent so that the chamber 106 and the chamber contents may be clearly viewed. As will be explained further below, a carrier 110 may be placed in the chamber 106 with the beneficial agent 108. This carrier 110 may be relatively inert and not dissolvable within the fluid flowing through the cartridge 82. For this reason, it may be hard to ascertain by visual inspection whether or not the entire dose of the beneficial agent 108 has been mixed and delivered to the fluid conduit downstream of the chamber. However, visual inspection of complete dosage delivery may be a good safeguard in the intravenous system 58.

Therefore, the housing 78 includes visual inspection means which, in addition to the optically transparent cartridge portion, may also include one or more hollow plastic spheres 129 or other floating visual indicator. In the preferred embodiment, several plastic spheres 129 are carried in the chamber 106, each floating in fluids having different ranges of specific gravity. An identical

set of spheres 129' are carried in the receiving segment 100. The receiving segment 100 of the receptacle 80 is also made optically transparent to view the spheres 129'. Because the beneficial agent does not enter the receiving segment 100, the number of spheres 129' floating in the receiving segment 100 will be dependent upon the specific gravity of the fluid from the fluid source.

The spheres 129' serve as a reference to determine when the agent has substantially all been mixed and delivered downstream of the chamber 106, by comparing the spheres 129 in the chamber with the spheres 129' in the receiving segment. When the same number of spheres 129, 129' remain floating in both the chamber 106 and the receiving segment 100, one knows that the specific gravities of the fluid in the chamber and the receiving segment 100 are substantially the same, so that at least almost all of the beneficial agent 108 has been transported downstream of the chamber 106. Until the agent 108, and the carrier 110 if dissolvable, leave the chamber 106 the specific gravity of the fluid in the chamber will be greater than the specific gravity of the fluid in the receiving segment, and hence more spheres 129 will be floating in the chamber than in the receiving segment.

Spheres may be disposed in the discharge segment 116 in addition to, or in place of, the spheres 129 in the chamber 106, in order to determine whether beneficial agent 108 remains in the fluid in the discharge segment or whether the agent 108 has passed downstream of the discharge segment. The discharge segment of the receptacle 78 would be optically transparent, and the spheres in the discharge segment 116 also could be compared with the spheres in the receiving segment 100.

The effect of downward flow in the receiving segment 100 on the location of the spheres 129' therein can be minimized by enlarging the volume of the receiving segment. Alternatively, the operator may, by means of the roller clamp 74 for example, momentarily stop fluid flow to compare the spheres 129, 129'.

Another embodiment of the visual indicator means is to inlcude spheres 129 only in the chamber 106 and not in the receiving and discharge segments 100, 116. In this embodiment, the floating specific gravity range for each sphere is preselected according to the beneficial agent 108, and the carrier if dissolvable, to be carried in the chamber 106. As mixing of the agent 108 nears completion, spheres begin to drop, providing an indication that mixing is nearing completion. After mixing of the agent 108 is complete and has been delivered out the chamber 106, the last sphere 129 drops.

Still another embodiment of the visual indicator means is to include a single sphere 129 in the chamber 106, once again floating in fluids down to a preselected minimum specific gravity, depending on the agent 108, and the carrier 110 if dissolvable. In this embodiment, as fluid flows through the chamber 106 and the last portion of the beneficial agent 108 is mixed and delivered downstream, the specific gravity of the fluid in the chamber becomes less and the sphere 129 begins to fall until coming to rest adjacent the bottom, upstream portion of the chamber 106. The visual indicator is intended to show whether or not substantially the entire dose has been mixed and delivered downstream.

Preferably, the floating spheres 129, 129' are made of a material to which small air bubbles do not easily adhere, so that the floating ability of the spheres 129 are not changed thereby.

Although the housing 78 described above facilitates passive drug reconstitution and delivers drug out the outlet 96 in the manner independent of the fluid flow rate through the housing 78, the housing 78, as above-described, does not solve the medically unacceptable problem of excessively high drug concentrations near the entry point into a patient's intravenous system at low flow rates, referred to as local toxicity. This problem is associated

with other known passive type drug delivery systems. Stated differently, the present apparatus 60 prevents a medically unacceptably high concentration of beneficial agent in the fluid delivered to the patient, thereby preventing serious vein irritation and any other medical problems associated with a toxic concentration of drug or other beneficial agent in the fluid entering the patient's intravenous system.

The apparatus 60 prevents local toxicity while also permitting delivery of the beneficial agent dose in a time period short enough to be medically acceptable. The apparatus 60 includes the housing 78 and means for controlling the rate of delivery of the beneficial agent out of the housing outlet 96. The control means creates two different delivery modes for the beneficial agent, depending upon the fluid flow rate out the outlet 96. The control means may include one or more of several structural features. In the apparatus 60 illustrated in FIGS. 3 and 4 for example, the control means includes pellets which include not only the beneficial agent 108 but also a carrier 110 such as a nondissolvable, porous polypropylene plastic, as will be explained in detail below.

The control means creates a first delivery mode in which the fluid velocity through the chamber 106 is high enough that the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through the chamber, providing all the advantages of flow rate independent agent delivery discussed above. Additionally, the control means also creates a second delivery mode in which the fluid velocity through the chamber is slow enough that the rate of delivery of the beneficial agent is dependent upon the fluid flow rate through the chamber. The first and second delivery modes include a fluid flow rate transition region between the higher fluid flow rates associated with the first delivery mode and the lower fluid flow rates associated with the second delivery mode.

In this fluid flow rate transition region the degree of dependence of the rate of beneficial agent delivery upon the fluid flow rate changes significantly.

Stated differently, in the first delivery mode the amount of beneficial agent delivered per unit time, for example grams per minute, is substantially a constant. At lower flow rates, in the second delivery mode, the amount of beneficial agent delivered per unit time becomes a variable and decreases as the fluid flow rate decreases.

The apparatus 60, including the control means, even prevents local toxicity if fluid flow is turned off entirely for extended time periods and then resumed at a low or a high flow rate. Multiple dosing, even at low flow rates, is made possible with the apparatus 60. For example, a fraction of the agent 108 in the chamber 106 may be delivered at flow rates low enough to be operating in the second delivery mode, for a given time period. Fluid flow can subsequently be turned off or turned to a lower flow rate. Another fraction of the available agent 108 can be delivered later, in the same manner, if desired.

Referring to FIG. 5 there is shown a graph illustrating the effect of the control means. The horizontal axis of the graph indicates the fluid flow rate and the vertical axis of the graph indicates the time required to deliver ninety percent of the available beneficial agent 108. The housing, beneficial agent and carrier used to generate this data are described below. Generally, in FIG. 5, the fluid flow rate transition region is between fluid flow rates of about thirty and sixty milliliters per hour. The first delivery mode begins in the fluid flow rate transition region and runs all the way to the highest flow rate tested, 240 ml/hour. Especially at flow rates at or above 60 ml/hour, the plotted line is substantially horizontal, representing the first delivery mode where the agent delivery rate is substantially independent of fluid flow rate.

The second delivery mode begins somewhere in the fluid flow rate transition region and extends down to 15 ml per hour, the lowest flow rate tested. The plotted line in this area of the graph is steeply sloped, representing the strong dependence of the agent delivery rate upon the fluid flow rate.

FIG. 6 is a cross-sectional view of an apparatus 168 including a housing 170 having an inlet 172 and an outlet 174 adapted for connection to upstream and downstream portions of a fluid conduit, respectively. The arrows illustrate the direction of fluid flow through the apparatus 168. The housing 170 was used to generate the data shown in the graph of FIG. 5.

The housing 170 includes an upper cup 176 secured to a lower cup 178 to form a chamber 171. The chamber 171 has a central cylindrical portion having an inner diameter of abut 3/4 inch and upper and lower conical portions defined by the upper and lower cups 176, 178 respectively. A lower metal screen mesh 180 is mounted at its periphery by friction fit, for example, to the lower cup 178, at the junction between the cylindrical and lower conical portions. The remainder of the screen mesh 180 is spaced from the lower cup 178. An upper metal screen mesh 181 is mounted at its periphery between the upper and lower cups 176, 178 for example. A tablet 182 rests on the lower screen mesh 180 and is held in position by the upper screen mesh 181. The tablet 182 includes a beneficial agent 184 and a carrier 186. As used in the test procedure, only for purposes of illustration, and not intended to limit the scope of the disclosure, the tablet 182 has a diameter of 9/16 inch and contains a 500 mg dose of sodium ampicillin as the beneficial agent 184. The tablet also includes as the carrier 186 a porous polypropylene plastic. The ratio by weight of sodium ampicillin to polypropylene plastic is about 10 to 1.

Before manufacture of the tablet 182, the polypropylene plastic existed in particles 188 having a mean particle size of approximately 53 microns ± 10 microns, although a wide variety of particle sizes are believed to work. A plastic particle 188 is illustrated schematically in FIG. 7. The plastic supply particles 188 are porous, having interconnecting voids 190 each of which is about 7 to 10 microns in diameter. The plastic particles 188 may be as manufactured by Armak Laboratories of McCook, Illinois under the name Accurel.

The tablet 182 is formed by compressing the sodium ampicillin 184 and the plastic supply particles 188 with a compression force of roughly 8,000 pounds per square inch, forming a structure illustrated schematically in FIGS. 8 and 9. It is believed that during compression of the formed tablet 182, some of the defined voids 190 in the individual plastic supply particles 188 are compressed. It is believed that the structure appears such as shown in FIG. 8, with beneficial agent particles 192 mixed in with the plastic supply particles 188. Except for voids 190 on the surface of the plastic supply particles 188, it is not believed that the beneficial agent 184 enters into the defined voids 190 in the plastic particles 188.

Referring now to FIG. 9, it is believed that because there is significantly more beneficial agent 184 than carrier 186 in the tablet 182, there are therefore created channels 194 of beneficial agent 184, comprising the compressed agent particles 192.

The convoluted channels 194 of beneficial agent 184 in the tablet 182 cause the beneficial agent to be metered out of the tablet 182 at a set rate, which is typically less than the beneficial agent's inherent rate of dissolution. This set rate, independent of flow rate in the first delivery mode, is controlled

by the compression force used in forming the tablet, thereby adjusting the void volume of the plastic particles 188, the void volume of the agent particles 192 and the void volume of the tablet 182. The set rate is further controlled by adjusting the surface area of the tablet, the weight ratio between the beneficial agent and the carrier, the particle size of the beneficial agent and the carrier and the shape of the tablet 182.

The greater the compression that is used in forming the tablet, the less will be the set rate. The smaller the surface area of the tablet exposed to fluid flow, the less will be the set rate. The lower the weight ratio of the beneficial agent to the carrier, the less will be the set rate. It is important to remember that the set rate is not an absolutely precise value, but that the set rate does not vary substantially above a certain flow rate, such as 60 ml/hour in the FIG. 5 example.

As illustrated in FIG. 6, fluid flowing through the housing 170 passes over the exterior surface of the tablet 182. Another flow arrangement is illustrated in FIG. 10, wherein there is shown a housing 196 defining a fluid pathway 198 in which is disposed a tablet 200 of a beneficial agent and a carrier. Fluid flow is from left to right in FIG. 10, which illustrates schematically what also happens in the apparatus 168 shown in FIG. 6. The tablets 182 and 200 permit the housings 170, 196 to utilize mass transfer concepts for producing a second delivery mode wherein the delivery rate of the beneficial agent is dependent upon the fluid flow rate.

The tablets 182, 200 present a mass transfer resistance to transport of the beneficial agent from the interior of the tablet to the surface of the tablet. This means the set delivery rate is less than the inherent rate of dissolution of the beneficial agent, as described above. Also, an additional resistance to mass transfer is presented by the diffusional boundary layer that exists from the

surface 202, 204 of each of the tablets 182, 200 respectively out a short distance "A" into the flowing fluid. The rate of mass transfer of the beneficial agent 184 through this diffusional boundary layer, designated by the thickness variable "A", depends upon the local velocity profile. The local velocity profile is in turn determined by such variables as the volume of fluid delivered through the pathway in a given time period, the cross-sectional area of the fluid pathway, particularly at the tablet, and the configuration of the fluid pathway cross-section. The left set of arrows in FIG. 10 schematically illustrate the local velocity profile at a relatively low flow rate while the right set of arrows in FIG. 10 illustrate the local velocity profile at a relatively high fluid flow rate, wherein the length of the arrows are proportional to the velocity of the fluid at that point in the fluid pathway cross-section.

Conforming with known principles of fluid dynamics, the fluid velocity is greater at the central portion of the fluid pathway and lower at the pathway walls such as defined for example by the housing wall 197 and the tablet surface 204. At lower flow rates, the change in fluid velocity at different points across the fluid pathway cross-section is less than at higher flow rates as indicated by the left and right sets of arrows respectively. By carefully matching the above-discussed tablet characteristics and the configuration of the fluid pathway in the apparatus 168 or the apparatus 60, below a certain fluid flow rate transition region the mass transfer resistance of the diffusional boundary layer is significant, i.e., the value of "A" is high in relation to the mass transfer resistance characteristic of the tablet 182, 200. At fluid flow rates above the transition region, the increased fluid velocity and the resulting greater change in the local velocity profile decrease the thickness "A" of the diffusional boundary layer enough

that essentially all of the mass transfer resistance results from the mass transfer resistance in the tablet 182, 200, not from the mass transfer resistance of the diffusional boundary layer. When this occurs the delivery rate of the beneficial agent becomes independent of the fluid flow rate.

Even more important is the ability to match the tablet and the above-described variables associated therewith to the fluid pathway in the apparatus 60, 168 to control the fluid flow rate range of the flow rate transition region. Stated differently, by changing the carrier, the beneficial agent, the fluid pathway and the interrelated characteristics as described above, it is not only possible to create a range of flow rate dependent agent delivery (second mode); the fluid flow rate region values where the agent delivery shifts from dependence upon to independence from fluid flow rate can also be controlled.

This ability to control the fluid flow rate transition region and to make the fluid flow rate transition region high enough to prevent local toxicity at low fluid flow rates in the apparatus 60,168 is a major distinction from other passive reconstitution systems.

At a given flow rate, two different apparatus 60, 168 can have two different local velocity profiles. Thus, the flow rates determining the flow rate transition region can be changed by varying the tablet, which may or may not have a carrier therein, in order to change its mass transfer resistance, or by changing the configuration of the fluid pathway in the housing 78, 170 and particularly the configuration of the chamber 106, 171 to change the local velocity profile and thus the thickness of the diffusional boundary layer.

The inherent rate of dissolution of the beneficial agent to be delivered and the carrier if any used therewith, and the resulting form, e.g., tablet, pellet or powder, in which the beneficial agent

is placed within the apparatus, will also determine the configuration and cross-sectional area of the fluid pathway in the apparatus across the surface area of the beneficial agent. The importance of the interaction of the mass transfer resistance provided by a diffusional boundary layer with the mass transfer resistance of the beneficial agent/carrier is illustrated by the horizontal line plotted in FIG. 5 just below the 17 minute mark. The line was plotted by using a tablet such as described above. The tablet was placed in a large vessel containing a liter of water which was stirred virgorously. Such an arrangement effectively eliminates any diffusional boundary layer around the beneficial agent. The horizontal line in the graph of FIG. 5 represents the intrinsic delivery rate of agent from the tablet as determined by the experiment in the large vessel. This intrinsic delivery rate is the rate approached by the first delivery mode in the example.

It is important to note that the apparatus 60, 168 need not have the beneficial agent or combination beneficial agent/carrier in tablet form only. Referring to FIG. 11, there is seen an apparatus 168' similar to the apparatus 168 of FIG. 6, except that it contains a beneficial agent 206 and a carrier 208 in pellet form. Each of the pellets 210 may be made like the individual tablet 182. For example, each pellet 210 may include sodium ampicillin and porous polypropylene. In operation, the apparatus 168' functions like the apparatus 168, except that the flow patterns 168 across and around the pellets 210 are more complex than the flow patterns around the tablet 182.

Referring to FIG. 12 there is illustrated an apparatus 168'' similar to the apparatus 168, 168', except that the chamber 171'' includes very small particles or powder of a beneficial agent 212 and a carrier 214. Continuing with the example, the agent 212 may be sodium ampicillin or another drug and the carrier 214 may be

porous polypropylene or a dissolvable sustance. In the apparatus 168'' of FIG. 12, the agent 212 particles and carrier 214 particles are provided separately into the chamber 171''. However, it would also be possible to combine the agent and carrier into small particles much smaller than the pellets illustrated in FIG. 11. It is believed that this will work better than the separate particles of agent and carrier. The flow patterns in the apparatus 168'' may even be more complex than the flow patterns operating in the apparatus 168 of FIG. 11. However, since the agent 212 and carrier 214 are not compressed together in the apparatus 168'', it is believed that the set rate of substantially flow rate independent agent delivery would be higher than in the apparatus 168', 168.

Furthermore, it is important to note that the pellet form and the powder form represented in FIGS. 11 and 12 may work as well in or even better in an upward directed fluid flowpath such as illustrated in by the apparatus 60 shown in detail in FIGS. 3 and 4.

Referring now to FIG. 13, there is illustrated an apparatus 216 similar to the apparatus 168. The apparatus 216 includes a tablet 218 comprising a beneficial agent 220 and a dissolvable carrier 222, such as mannitol. The beneficial agent may be sodium ampicillin. In this example, the amount of carrier necessary is much higher than with the nondissolvable carrier. For example the weight ratio of carrier 222 to beneficial agent 220 may be 10:1. The control means operates such as described above, including reliance upon a larger diffusional boundary layer at lower flow rates to create a second delivery mode of flow rate dependent agent delivery. At higher flow rates agent delivery is substantially independent of fluid flow rate. However, since the carrier 222 dissolves along with the agent 220, the maximum rate of agent dissolution is controlled less by the mass transfer resistance created by the tablet 218 and more by the solubility of the carrier 222 competing with the agent 220 for the available fluid. Stated differently, with a dissolvable carrier 222

the intrinsic rate of dissolution of the tablet 218 most likely replaces the mass transfer resistance of the tablet 182 as the critical factor in determining maximum agent delivery rate.

It is believed that the combined beneficial agent 220 and dissolvable carrier 222 may be employed in powder and pellet form as illustrated in FIGS. 11 and 12 for a nondissolvable carrier. In addition, the combination of an agent 220 with a dissolvable carrier 222 may be used in the apparatus 60.

With both a nondissolvable carrier and a dissolvable carrier it is important not only to have a properly sized flowpath across and around the agent, but also important to limit the size of the chamber in which the agent is stored, thereby limiting the amount of dissolved concentrated agent present within the cartridge.

It is believed that with either a dissolvable or nondissolvable carrier, the powder form illustrated in FIG. 12 is more sensitive than either the pellet or tablet form to increased flow rates, because the greater turbulence caused by greater flow rate will have a greater effect upon increasing the rate of agent dissolution in the powder form. Also, it is believed that with the powder form the fluid flow rate transition region may be harder to control.

It is believed that a dissolvable carrier 222 may create a system which is more influenced by an increased flow rate than an insoluble carrier; however, use of a dissolvable carrier does ensure a substantially constant agent delivery rate over time at higher flow rates.

One advantage of a dissolvable carrier 222 is that it provides a visual indicator of whether or not the dose of beneficial agent 222 has been delivered out of the apparatus 60, 168. For example, the tablet 218, having a dissolvable carrier may be placed in the cartridge 82 of the apparatus 60. The cartridge 82 may be optically transparent to enable viewing of the chamber 106. A nurse or other operator could tell that the agent 220 had been substantially

delivered by noting that the tablet 218 had dissolved. Such an arrangement may eliminate the need for the hollow plastic sphere 129 or other floating indicator.

Referring now to FIG. 14, there is schematically illustrated a split fluid pathway having two non-series connecting fluid pathway segments 224a, 224b in a fluid pathway of an apparatus 226. The schematically illustrated apparatus 226 includes a beneficial agent 228 in loose powder form for example, trapped between screen mesh 230 for example. FIG. 14 illustrates the use of a split flow path to help create a second delivery mode high enough to prevent local agent toxicity in the fluid delivered to a patient. By properly sizing the non-series connecting segments 224a, 224b, the apparatus 226 may be designed so that at a flow rate of 60 ml/hour for example, 20 ml/hour goes through segment 224a and 40 ml/hour flows through segment 224b. Because of resistance caused by the beneficial agent 228 in the segment 224a, the segment 224b may have a much smaller cross-sectional area.

With this construction, raising the fluid flow rate from 60 to 120 ml/hour would result in approximately 40 ml/hour through the segment 224a and 80 ml/hour through the segment 224b. Similarly, lowering the fluid flow rate to 30 ml/hour would result in approximately 10 ml/hour through the segment 224a and 20 ml/hour through the segment 224b. Depending on the inherent rate of dissolution of the beneficial agent 228, the delivery of agent 228 out the outlet 232 at flow rates of 60 and 120 ml/hour may be independent of fluid flow rate, whereas at the lower flow rate of 30 ml/hour, the flow of liquid through the segment 224b may become determinative of the agent delivery rate, so that agent delivery becomes dependent upon the fluid flow rate.

It will be seen that with the split-flow arrangement of the apparatus 226, the restriction of fluid flow across the segment 224a may vary greatly over time, as the beneficial agent 228 dissolves.

The effect of this change may be decreased by employing a nondissolvable carrier or it may be hard to develop such a construction without blocking flow through the segment 224a entirely. Thus, it may be seen that the apparatus 226 is better directed to the delivery of a beneficial agent 228 over much longer time periods such as for example twenty-four hours. By so doing, the change in fluid flow resistance through the segment 224a will be less per unit time, allowing for a more substantially flow rate independent agent delivery at flow rates at or above a certain desired value.

FIG. 15 illustrates an apparatus 234 which is similar in appearance to the apparatus 60 shown in FIGS. 3 and 4, but which functions quite differently. The apparatus 234 employs the split-flow fluid pathway as discussed with reference to the apparatus 226. When the cartridge 82' is plugged into the receptacle 80' without a flow director, some fluid continues to flow out the outlet 96', without first flowing through the cartridge 82' with a beneficial agent 236 therein. The apparatus 234 is not preferred, especially for smaller agent delivery time periods such as about thirty minutes.

It is important to note that the agent or agent/carrier combination placed in the chamber of the apparatus 60, 168, 168', 168'', 216, 226, 234 may include other configurations and, when correctly matched with the proper flowpath for creation of a specific local velocity profile and diffusional boundary layer, comprise control means creating a second delivery mode which extends to fluid flow rates high enough to prevent local agent toxicity. For example, the agent and carrier may comprise drug particles essentially completely coated by polymer. Another possibility is drug contained in an internal tablet-sized mass transfer conductor or reservoir, said conductor or reservoir surrounded by an outer, rate controlling membrane. Fluid flow would be directed over the

membrane. Further possibilities include bio-erodible or water-erodible carriers containing agent particles wherein the products of the erosion inhibit further net erosion, and agent particles with a non-dissolvable carrier wherein a tortuous agent release pathway is created. Still further possibilities of carrier types and carrier/agent combinations are illustrated in U.S. Patent Nos. 4,424,056; 4,432,756; and 4,439,183 for example.

Referring now to FIGS. 16 and 17, there is illustrated an apparatus 238 for placement in an intravenous delivery system such as shown in FIG. 1, replacing the apparatus 60. A fluid conduit such as plastic tubing 76' includes upstream tubing portion 76a' adapted for connection to a fluid source and downstream tubing portion 76b' adapted for fluid communication with a patient's intravenous system.

The apparatus 238 includes a housing 240 having a receptacle 242 including an inlet 244 connected to the upstream portion 76a' of the fluid conduit and an outlet 246 connected to the downstream portion 76b' of the fluid conduit. The receptacle 242 may be an injection site of virtually standard construction, such as the "Y" adapter injection site 36 shown in the prior art system of FIG. 2.

The housing 240 includes a separate cartridge 248 which is plugged into the receptacle 242 to form the complete housing 240. The housing 240 may also be constructed so that the cartridge 248 and the receptacle 242 are a unit.

Like the housing 78, the housing 240 defines a fluid pathway 250 therethrough. The inlet 244 and the outlet 246 define part of the fluid pathway 250. The fluid pathway forms part of the fluid conduit of the intravenous delivery system.

The housing includes a fluid receiving segment 252 having an upstream end 254 in fluid communication with the inlet 244, and a downstream end 256. A chamber 258 adapted for receiving a beneficial agent 260 and a carrier 262, such as pellets 264 of

sodium ampicillin and porous polypropylene for example, is defined by the cartridge 248. The chamber 258 defines part of the fluid pathway 250 in the housing 240.

The receptacle 242 preferably includes a handle 243 for grasping the receptacle 242 when attaching the cartridge 248. The receptacle 242 includes a polyisoprene or other puncturable, resealable situs 266 closing off an access volume 268 defined by the wall 270 of the receptacle 242. The wall 270 also defines a narrower channel 272 adjacent the outlet 246.

The cartridge 248 includes a double bore needle 274 adapted for piercing the receptacle situs 266. The double bore needle 274 is mounted to the cartridge wall 276 so that both bores of the needle 274 are in communication with the chamber 258. A cartridge sleeve 278 mounted about and spaced from the double bore needle 274 prevents touch contamination of the needle 274 and assures a secure fit of the cartridge 248 to the receptacle 242. A slot 280 in the sleeve 278 fits around the fluid receiving segment 252 of the receptacle 242. A tip protector 282 closes the sleeve 278 and double bore needle 274 during storage and is removed before attaching the cartridge to the receptacle.

The cartridge 248 further includes a holding loop 284 for securing the cartridge to the upstream tubing portion 76a'.

The chamber 258 includes a chamber upstream end 286 adapted for fluid communication with the receiving segment downstream end 256, and a chamber downstream end 294, opposite the upstream end 286.

The first and second bores 290, 298 of the double bore needle 274, along with the situs 266, form connecting means for securing the cartridge 248 to the receptacle 242 and providing for fluid flow therebetween. The connecting means includes first and second cross-over segments which correspond to the first and second bores 290, 298. The first cross-over segment, in this case the first bore

290, is disposed between and adapted for providing fluid communication between the receiving segment downstream end 256 and the chamber upstream end 286.

In the housing 240 the second cross-over segment, in this case the second bore 298, comprises the discharge segment 296, so that the second cross-over segment is disposed between and adapted for fluid communication between the chamber downstream end 294 and the outlet 246. The discharge segment 296 includes a discharge segment upstream end 300 which is the open end of the second bore 298 within the chamber 258, adapted for fluid communication with the chamber downstream end 294. The discharge segment downstream end 302 is defined by the open distal end 304 of the second bore 298.

The access volume 268, as closed by the situs 266, also forms part of both the first and second cross-over segments. Thus, the first and second cross-over segments are each disposed in both the receptacle 242 and the cartridge 248.

The situs 266 comprises puncturable means. The closed distal end 288 of the first bore 290 and the open distal end 304 of the second bore 298, all being part of the double bore needle 274, comprise the puncturing means.

When the cartridge 248 is not plugged into the receptacle 242, fluid flowing from the fluid source through the fluid conduit 76' flows through the housing inlet 244 and into the receiving segment 252. The fluid flows out the receiving segment downstream end 256, whereupon it continues to flow out the outlet 246 into the downstream portion 76b' of the tubing 76'.

When the cartridge 248 is plugged into the receptacle 242 such that the chamber 258 is in fluid communication with the receiving segment 252 and the discharge segment 296, the double bore needle 274 seals against the narrower channel 272 within the receptacle 242 so that fluid entering the receiving segment 252 does not exit immediately into the outlet 246 but must instead first enter the

double bore needle 274. Fluid flows from the receiving segment downstream end 256 into the first side opening 292 of the first bore 290 and up the first bore 290. Fluid exits the first bore 290 at the second side opening 293 of the first bore 290, into the chamber 258 at the chamber upstream end 286. The fluid flows up through and around the beneficial agent 260 and carrier 262 upwardly to adjacent the chamber upstream end 294, whereupon it begins to flow downwardly through the discharge segment 296 and then through the outlet 246.

The beneficial agent 260 may be combined with a carrier 262 and may be in powder, pellet, tablet or other form. The carrier may be dissolvable or non-dissolvable. When the limits of agent dissolution provided by the tablet, pellet, powder or other agent or agent/carrier configuration are combined with the limitations of the flowpath in the housing 240, the apparatus 238 thereby includes control means necessary to push the fluid flow rate transition region up into a flow rate range permitting flow rate dependent agent delivery at flow rates high enough to prevent local toxicity.

Even without the control means the housing 240 permits passive drug reconstitution and includes all the advantages provided by an upward flowpath as discussed with reference to the housing 78. Similar to the housing 78, the housing 240 allows for delivery of the beneficial agent 260 in a time period short enough to be therapeutically effective. However, the housing 240 prevents the drug from being delivered too quickly at high flow rates so that the medically unacceptable condition of systemic toxicity will not occur.

As with the housing 78, it is believed that air eliminating means should be included in the fluid conduit of the intravenous delivery system including the housing 240. However, as with the housing 78, the air eliminating means need not be disposed within the housing 240 itself, but rather may be disposed downstream of the housing.

As with the housing 78, the housing 240 may be designed for shipment to a hospital with the beneficial agent therein, or designed for agent filling at the hospital.

The slot 280 in the cartridge sleeve 278 along with the sleeve 278 itself provides a key way to assure that the first side opening 292 is disposed facing the upstream tubing portion 76', although it is believed that even if the first side opening 292 were rotated 180° the housing 240 would still function properly.

Referring now to FIGS. 18 and 19 there is disclosed yet another housing 306, including a receptacle 80 which may be identical to the receptacle in the housing 78. The receptacle 80 is mounted "in-line" in an intravenous delivery system between upstream and downstream portions 76a'', 76b'' respectively of plastic tubing 76''.

The housing 306 includes a separate receptacle 80, intermediate portion 308 and cartridge 310. The cartridge 310 may be a drug vial of standard construction. The ability to use a drug vial of standard construction represents one of the advantages of the housing 306. FIG. 18 illustrates the three separate units. Before the three units are connected, fluid flows through the receiving segment 100 from the inlet 94 to the outlet 96. FIG. 19 illustrates the housing 306 with the three units 80, 308, 310 connected so that virtually all fluid which flows out of the outlet 96 first flows through all three of the receiving segment 100, the chamber 312 defined by the cartridge 310, and the discharge segment 116, forming a fluid pathway in the housing 306.

When the cartridge 310 is a drug vial of standard construction, it typically includes an optically transparent glass wall 314 defining the chamber 312 and a container neck 316. A stopper 318 or situs of rubber or other puncturable, resealable material is mounted within the mouth 320 defined by the neck 316. A metal band 322 is secured about the mouth 320, retaining the stopper 318 in the cartridge 310.

Connecting means allow for fluid communication between the receptacle 80, the intermediate portion 308 and the cartridge 310. The connecting means includes first and second cross-over segment 324, 326. Portions of both the first and second cross-over segments are included in the receptacle 80. Injection sites 126, 128 block the first and second cross-over segments 324, 326 in the receptacle 80 and serve as the puncturable means as described above with reference to the housing 78. Puncturing means for the injection sites 126, 128 include first and second intermediate cannulas 328, 330 mounted within the intermediate portion 308 and serving as part of the first and second cross-over segments 324, 326 respectively. The intermediate portion 308 includes sleeves 332, 334 mounted about and spaced from the portions of the cannulas 328, 330 respectively which pierce the injection sites 126, 128, preventing touch contamination.

When disposed as shown in FIG. 19, the chamber upstream end 336 is adjacent the rubber stopper 318 and the chamber downstream end 338 is the end opposite the stopper. The first and second cross-over segments 324, 326 include sharpened vial ends 340, 342 for puncturing the stopper 318. The first cross-over segment vial end 340 is sized so as to just pierce the stopper 318, projecting just slightly into the chamber 312. The second cross-over segment vial end 342 projects much further into the chamber 312, closer to the chamber downstream end 338.

The cartridge 310 includes a beneficial agent 344 which is most commonly in a powder form and, as shown in FIG. 19, is disposed within the cartridge neck 316 which has a natural funnel-like configuration.

By placing the first cross-over segment vial end 340 barely within the chamber, a turbulant flow pattern is created around the beneficial agent 344. By placing the second cross-over segment vial end 342 well within the chamber 312, vertically spaced from the first segment vial end 340, an upward flow pattern is created within the chamber 312.

The first cross-over segment 324 provides fluid flow communication between the receiving segment downstream end 104 and the chamber upstream end 336. The second cross-over segment 326 provides for fluid communication between the chamber downstream end 338 and the discharge segment upstream end 118.

The distance between the second segment vial end 342 and the chamber upstream end 336, noted as distance "D", along with the volume of the chamber 312 are two factors which determine the concentration of agent in fluid flowing into the second cross-over segment vial end 342, downstream to the outlet 96. It should be noted that the critical distance "D" also corresponds to the distance between the second side opening 293 and the discharge segment upstream end 300 in the housing 240 of FIGS. 16 and 17.

Raising the first segment vial end 340 will lessen turbulence through the beneficial agent 344 stored in the chamber, lessening the mixing action and thereby relying more on the inherent dissolution rate of the beneficial agent 344 for mixing the agent 344 with the fluid. In addition, the solubility of the beneficial agent and the dose of agent 344 within the chamber may also determine the appropriate distance between the second segment vial end 342 and the stopper 318 (distance "D"), in order to deliver the agent dose within a therapeutically acceptable time period. Listed below are agent, dosage and approximate needle distance "D" and

vial (cartridge) volume for each of four drugs tested with a similar housing 306, for delivery of the agent within the prescribed time periods.

Drug	Dose	Distance "D"	Vial Volume
Ampicillin	1 gm	2"	10cc
Ampicillin	2 gm	2"	20cc
Cephalothin	1 gm	1"	10cc
Cephalothin	2 gm	1 1/2"	20cc
Cefazolin	0.5 gm	1 1/2"	10cc
Cefazolin	1 gm	1 1/2"	10cc
Cefazolin	2 gm	1 1/2"	20cc
Ticarcillin	1 gm	1"	20cc
Ticarcillin	2 gm	1 1/2"	20cc
Ticarcillin	3 gm	2"	30cc

The above data are intended to be examples only and may vary. Different needle lengths in the same vial volume for the same dosage weights of different drugs are necessitated because of different drug solubilities and rates of dissolution.

The housing 306 may also be constructed in a manner such as would be represented by turning the intermediate portion 308 and the cartridge 310 upside down with respect to the receptacle 80, so that the second cannula 330 is upstream of the first cannula 328.

Furthermore, while the housing 306 is intended for use with a standard drug vial as the cartridge 310, which vials typically have powdered drug therein, the cartridge 310 can instead store a tablet, pellets, powder or other configuration of beneficial agent and carrier as discussed above.

Furthermore, it may be possible, by controlling the variables of chamber volume, cross-sectional configuration of the flow path and locations of the cross-over segment vial ends 340, 342 to create an apparatus which includes the necessary control means to create both first and second delivery modes where the second delivery mode of flow rate dependent agent delivery is at flow rates medically acceptably high enough to prevent local toxicity of agent.

As with the housing 78, the intravenous delivery system including the housing 306 should also include air eliminating means, preferably downstream of the housing 306.

The housing 306 permits passive agent reconstitution and permits the use of standard drug vials used by many companies to contain drugs.

While several embodiments and features have been described in detail herein and shown in the accompanying drawings, it will be evident that various further modifications are possible without departing from the scope of the invention.

WHAT IS CLAIMED IS:

Claim 1. Apparatus into which a beneficial agent is placed for the safe delivery of the beneficial agent to a patient, when said apparatus is placed in an intravenous delivery system including a fluid source and a fluid conduit, said apparatus comprising:

(a) a housing defining a chamber adapted for receiving a beneficial agent, said chamber having a fluid pathway therethrough, said housing including an inlet and an outlet defining part of said fluid pathway, said fluid pathway, said inlet and said outlet adapted for forming part of the fluid conduit to the patient; and

(b) means for controlling the rate of delivery of the beneficial agent out of said outlet, said control means being capable of producing first and second delivery modes for the beneficial agent, such that in said first delivery mode the fluid flow rate through said chamber is high enough that the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through said chamber, and such that in said second delivery mode, the fluid flow rate through said chamber is slow enough that the rate of delivery of the beneficial agent is at least partially dependent upon the fluid flow rate through said chamber.

Claim 2. Apparatus for the safe delivery of a beneficial agent to a patient, comprising:

(a) a housing defining a chamber adapted for receiving a beneficial agent, said chamber having a fluid pathway therethrough, said housing including an inlet and an outlet defining part of said fluid pathway; and

(b) means for controlling the rate of delivery of the beneficial agent out of said outlet, said control means being capable of producing first and second delivery modes for the beneficial agent, such that in said first delivery mode the fluid flow rate through said chamber is high enough that the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through said chamber, and such that in said second delivery mode, the fluid flow rate through said chamber is slow enough that the rate of delivery of the beneficial agent is at least partially dependent upon the fluid flow rate through said chamber.

Claim 3. Apparatus for the safe delivery of a beneficial agent to a patient, comprising:

(a) a fluid conduit having proximal and distal ends, said proximal end being adapted for communicating with a fluid source, said distal end being adapted for communicating with the intravenous system of the patient;

(b) a housing interposed in and forming part of said fluid conduit, said housing defining a chamber adapted for receiving a beneficial agent, said chamber having a fluid pathway therethrough, said housing including an inlet and an outlet defining part of said fluid pathway, said fluid pathway being in fluid communication with said fluid conduit at both said inlet and said outlet; and

(c) means for controlling the rate of delivery of the beneficial agent out of said outlet, said control means being capable of producing first and second delivery modes for the beneficial agent, such that in said first delivery mode, the fluid flow rate through said chamber is high enough that the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through said chamber, and such that in said second delivery mode, the fluid flow rate through said chamber is low enough that the rate of delivery of the beneficial agent is at least partially dependent upon the fluid flow rate through said chamber.

Claim 4. Apparatus for the safe delivery of a beneficial agent to a patient, when said apparatus is placed in an intravenous delivery system including a fluid source and a fluid conduit, said apparatus comprising:

(a) a housing defining a chamber having a fluid pathway therethrough, said housing including an inlet and an outlet defining part of said fluid pathway, said fluid pathway, said inlet and said outlet adapted for connection to the fluid conduit of the intravenous delivery system such that said fluid pathway forms part of the fluid conduit;

(b) a beneficial agent within said chamber; and

(c) means for controlling the rate of delivery of said beneficial agent out of said outlet, said control means being capable of producing first and second delivery modes for said beneficial agent, such that in said first delivery mode, the fluid flow rate through said chamber is high enough that the rate of delivery of said beneficial agent is substantially independent of the fluid flow rate through said chamber, and such that in said second delivery mode, the fluid flow rate through said chamber is low enough that the rate of delivery of said beneficial agent is at least partially dependent upon the fluid flow rate through said chamber.

Claim 5. Apparatus for the safe delivery of a beneficial agent to a patient, when said apparatus is placed in an intravenous delivery system including a fluid source and a fluid conduit, said apparatus comprising:

(a) a housing defining a chamber having a fluid pathway therethrough, said housing including an inlet and an outlet defining part of said fluid pathway, said fluid pathway, said inlet and said outlet adapted for connection to the fluid conduit of the intravenous delivery system such that said fluid pathway forms part of the fluid conduit;

(b) a beneficial agent within said chamber;

(c) a carrier for said beneficial agent, within said chamber;

(d) means for controlling the rate of delivery of said beneficial agent out of said outlet, said control means being capable of producing first and second delivery modes for said beneficial agent, such that in said first delivery mode, the fluid flow rate through said chamber is high enough that the rate of delivery of said beneficial agent is substantially independent of the fluid flow rate through said chamber, and such that in said second delivery mode, the fluid flow rate through said chamber is low enough that the rate of delivery of said beneficial agent is at least partially dependent upon the fluid flow rate through said chamber.

Claim 6. The apparatus in accordance with Claims 1, 2 or 3, further comprising the beneficial agent within said chamber.

Claim 7. The apparatus in accordance with Claim 4, further comprising a carrier for said beneficial agent, within said chamber.

Claim 8. The apparatus in accordance with Claim 6, further comprising a carrier for said beneficial agent, within said chamber.

Claim 9. The apparatus as in Claims 1, 2, 3, 4 or 5, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a locally toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 10. The apparatus as in Claim 6, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a locally toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 11. The apparatus as in Claim 7, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a locally toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 12. The apparatus as in Claim 8, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a locally toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 13. The apparatus in accordance with Claim 9, in which the flow rate transition region is low enough to prevent a systemically toxic concentration of a beneficial agent in the blood stream of the patient.

Claim 14. The apparatus in accordance with Claim 10, in which the flow rate transition region is low enough to prevent a systemically toxic concentration of a beneficial agent in the blood stream of the patient.

Claim 15. The apparatus in accordance with Claim 11, in which the flow rate transition region is low enough to prevent a systemically toxic concentration of a beneficial agent in the blood stream of the patient.

Claim 16. The apparatus in accordance with Claim 12, in which the flow rate transition region is low enough to prevent a systemically toxic concentration of a beneficial agent in the blood stream of the patient.

Claim 17. The apparatus in accordance with Claim 1, 2, 3, 4 or 5, in which said control means includes a first delivery mode enabling a therapeutic dose of the beneficial agent to be delivered in a time period not greater than the maximum therapeutically acceptable time period.

Claim 18. The apparatus in accordance with Claim 9, in which said control means includes a first delivery mode enabling a therapeutic dose of the beneficial agent to be delivered in a time period not greater than the maximum therapeutically acceptable time period.

Claim 19. The apparatus in accordance with Claim 10, in which said control means includes a first delivery mode enabling a therapeutic dose of the beneficial agent to be delivered in a time period not greater than the maximum therapeutically acceptable time period.

Claim 20. The apparatus in accordance with Claim 11, in which said control means includes a first delivery mode enabling a therapeutic dose of the beneficial agent to be delivered in a time period not greater than the maximum therapeutically acceptable time period.

Claim 21. The apparatus in accordance with Claim 12, in which said control means includes a first delivery mode enabling a therapeutic dose of the beneficial agent to be delivered in a time period not greater than the maximum therapeutically acceptable time period.

Claim 22. The apparatus in accordance with Claim 17, in which said first delivery mode enables a therapeutic dose of the beneficial agent to be delivered in a time period of approximately thirty minutes.

Claim 23. The apparatus in accordance with Claim 18, in which said first delivery mode enables a therapeutic dose of the beneficial agent to be delivered in a time period of approximately thirty minutes.

Claim 24. The apparatus in accordance with Claim 19, in which said first delivery mode enables a therapeutic dose of the beneficial agent to be delivered in a time period of approximately thirty minutes.

Claim 25. The apparatus in accordance with Claim 20, in which said first delivery mode enables a therapeutic dose of the beneficial agent to be delivered in a time period of approximately thirty minutes.

Claim 26. The apparatus in accordance with Claim 21, in which said first delivery mode enables a therapeutic dose of the beneficial agent to be delivered in a time period of approximately thirty minutes.

Claim 27. The apparatus in accordance with Claim 9, in which said control means comprises the cross-sectional area of said fluid pathway.

Claim 28. The apparatus in accordance with Claim 9, in which said control means comprises the local velocity profile of fluid passing over the beneficial agent.

Claim 29. The apparatus in accordance with Claim 9, in which said control means comprises the thickness of the diffusional boundary layer of the fluid passing over the beneficial agent.

Claim 30. The apparatus in accordance with Claim 9, in which said control means comprises a plurality of non-series connecting fluid pathway segments forming said fluid pathway, in which at least one fluid pathway segment is exclusive of flow-path communication with the beneficial agent.

Claim 31. The apparatus as in Claims 4 or 5, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 32. The apparatus in accordance with Claim 31, wherein said control means comprises the percentage of void volume of said beneficial agent.

Claim 33. The apparatus in accordance with Claim 31, wherein said control means comprises the rate of dissolution of said beneficial agent.

Claim 34. The apparatus in accordance with Claim 31, wherein said beneficial agent comprises separable particles and wherein said control means comprises the particle size of said beneficial agent.

Claim 35. The apparatus in accordance with Claim 31, wherein said control means comprises the amount of surface area of said beneficial agent in contact with fluid flowing through said fluid pathway.

Claim 36. The apparatus in accordance with Claim 31, in which said control means comprises the shape of said beneficial agent within said chamber.

Claim 37. The apparatus in accordance with Claim 5, in which said control means causes said first and second delivery modes to be separated at a fluid flow rate transition region high enough to prevent a toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 38. The apparatus in accordance with Claim 37, in which said control means comprises the weight ratio of said beneficial agent to said carrier.

Claim 39. The apparatus in accordance with Claim 37, in which said control means comprises the percentage of void volume of said carrier with said beneficial agent therein.

Claim 40. The apparatus in accordance with Claim 37, in which said control means comprises the percentage of void volume of said carrier as measured without said beneficial agent therein.

Claim 41. The apparatus in accordance with Claim 37, in which said carrier is dissolvable and in which said control means comprises the rate of dissolution of said carrier.

Claim 42. The apparatus in accordance with Claim 41, wherein at least a portion of said housing defining said chamber is optically transparent and further wherein total dissolution of said carrier and said agent provides a visual indication that said agent has been successfully mixed and delivered downstream of said chamber.

Claim 43. The apparatus in accordance with Claim 37, in which said carrier includes separable particles and in which said control means comprises the size of said carrier particles.

Claim 44. The apparatus in accordance with Claim 37, wherein said control means comprises the amount of surface area of said carrier, with said beneficial agent therein, in contact with fluid flowing through said fluid pathway.

Claim 45. The apparatus in accordance with Claim 37, in which said control means comprises the shape of said carrier, with said beneficial agent therein.

Claim 46. The apparatus as in Claim 37, wherein said carrier is mannitol.

Claim 47. The apparatus as in Claim 37, wherein said carrier comprises a porous polypropylene tablet.

Claim 48. The apparatus as in Claim 37, wherein said carrier comprises polypropylene beads.

Clain 49. The apparatus in accordance with Claim 37, in which said control means comprises the thickness of the diffusional boundary layer of the fluid passing over said agent.

Claim 50. The apparatus in accordance with Claim 37, in which said control means comprises the thickness of the diffusional boundary layer of the fluid passing over said carrier.

Claim 51. The apparatus in accordance with Claim 37, in which said control means comprises the thickness of the diffusional boundary layer of the fluid passing over said agent and said carrier.

Claim 52. The apparatus in accordance with Claim 37, in which said carrier does not dissolve.

Claim 53. A method for mixing a beneficial agent with a fluid and safely delivering the agent to a patient, the steps comprising:

(a) providing an intravenous delivery system including a fluid source and a fluid conduit connected to the fluid source for delivering fluid in the source to the patient;

(b) providing a housing within the fluid conduit, the housing defining a chamber with the beneficial agent therein, the chamber having a fluid pathway therethrough in fluid communication with the fluid conduit both upstream and downstream of the housing; and

(c) automatically controlling the rate of delivery of the beneficial agent out of the housing outlet, said control step including

(i) producing a first delivery mode in which the rate of delivery of the beneficial agent is substantially independent of the fluid flow rate through the chamber,

(ii) producing a second delivery mode at fluid flow rates lower than the first delivery mode, in which the rate of delivery of the beneficial agent is at least partially dependent upon the fluid flow rate through the chamber and

(iii) separating the first and second delivery modes at a fluid flow rate transition region high enough to prevent a toxic concentration of beneficial agent in the fluid delivered to the patient.

Claim 54. The method as in Claim 53, wherein said control step further comprises producing a first delivery mode such that the rate of delivery of the beneficial agent is low enough to prevent a toxic concentration of beneficial agent in the bloodstream of the patient.

FIG. 1

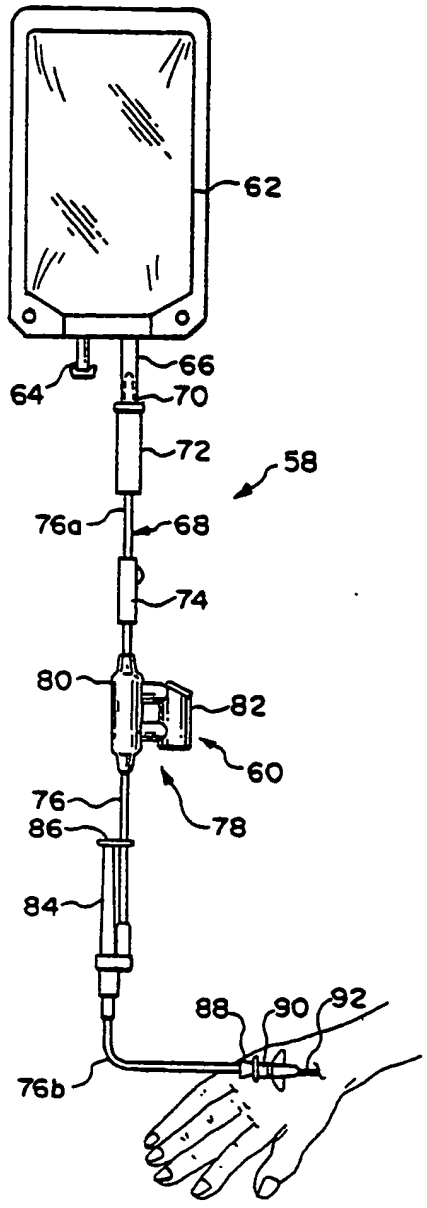


FIG. 2
PRIOR ART

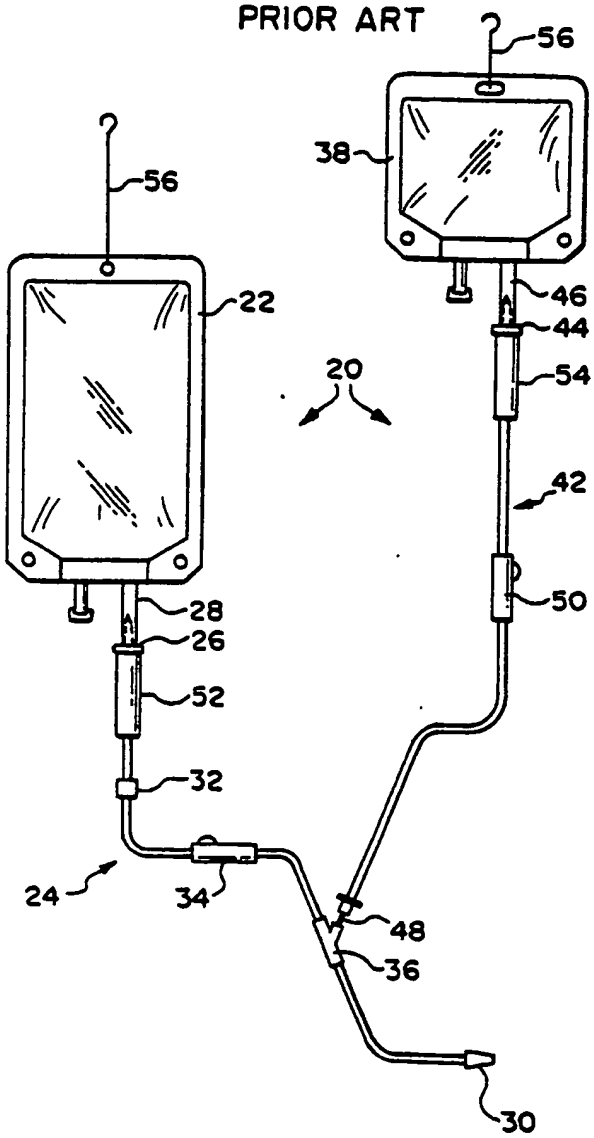


FIG. 3

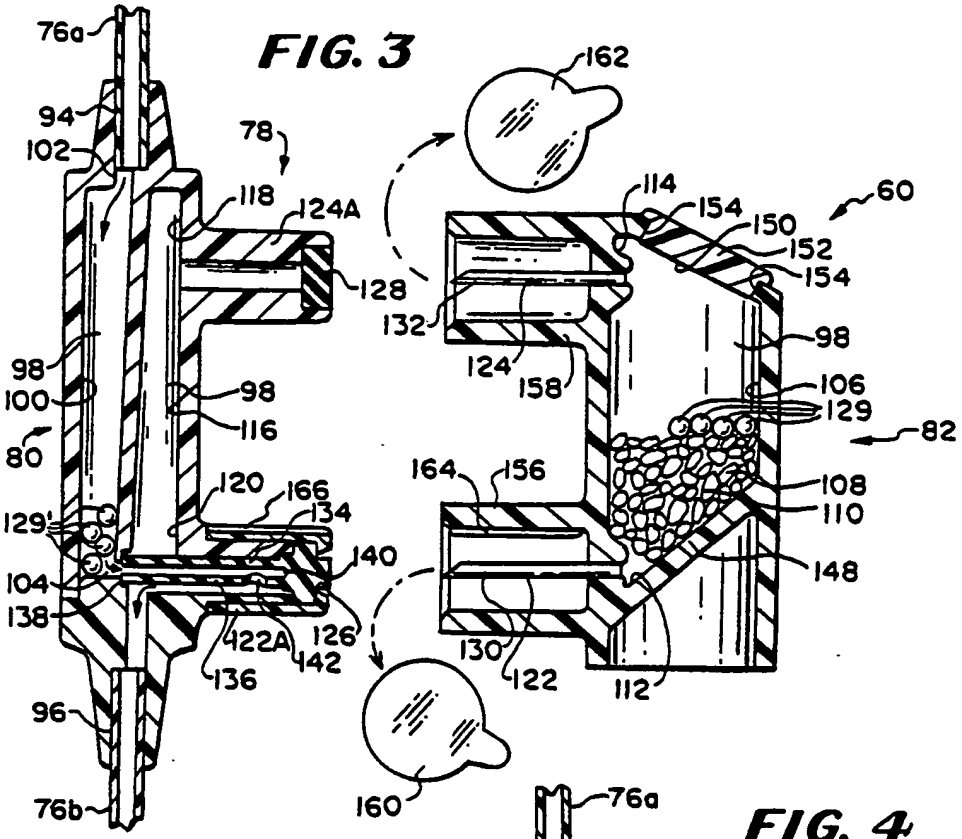
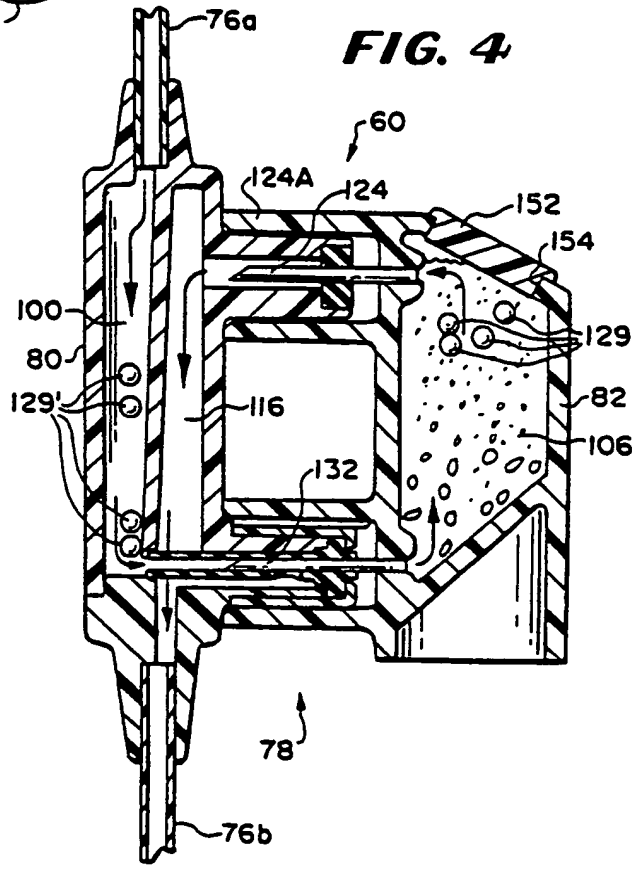

76a
94
102
78
118
124A
128
162
114
154
150
152
154
60
132
124
158
98
106
129
82
98
100
80
98
116
120
166
134
164
156
108
110
129'
104
138
140
148
422A
126
142
136
130
122
112
96
76b
160

FIG. 4


76a
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124A
124
152
154
100
80
129'
116
129
82
106
132
78
76b

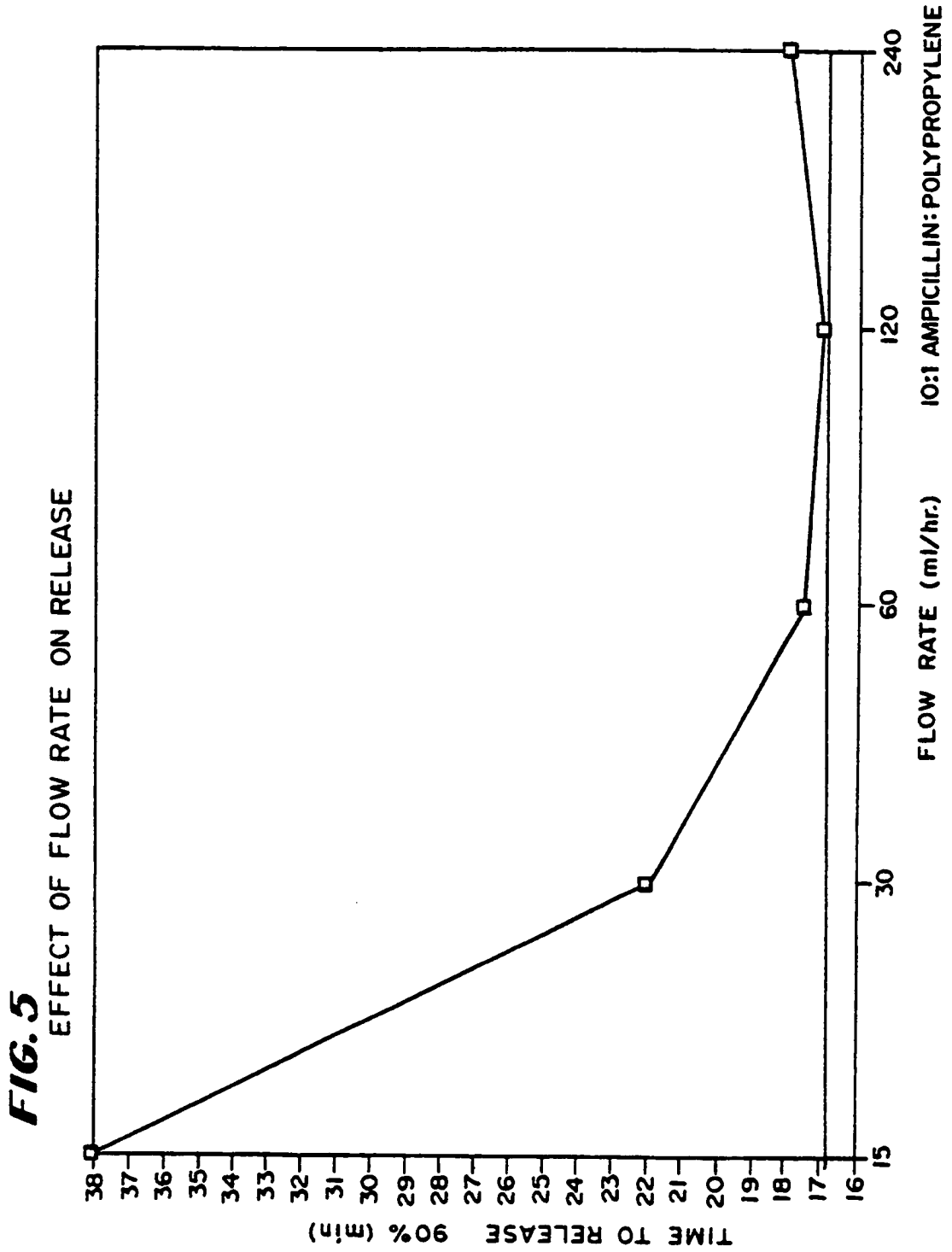

EFFECT OF FLOW RATE ON RELEASE
10:1 AMPICILLIN:POLYPROPYLENE
FLOW RATE (ml/hr.)
15
30
60
120
240
TIME TO RELEASE 90% (min)
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

FIG. 5

FIG. 6

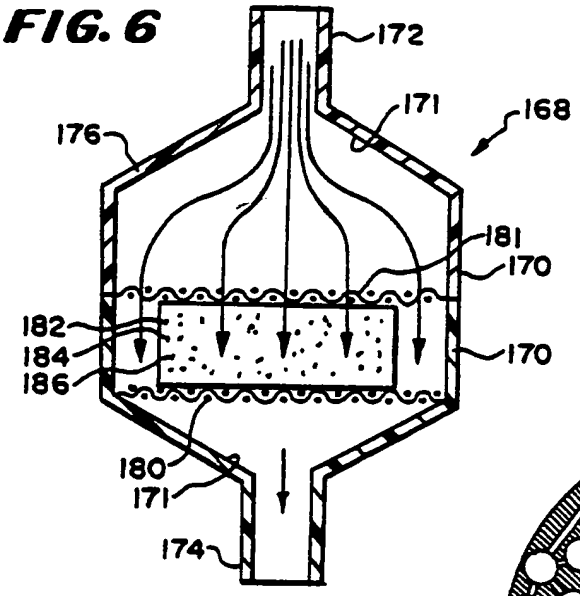


FIG. 7

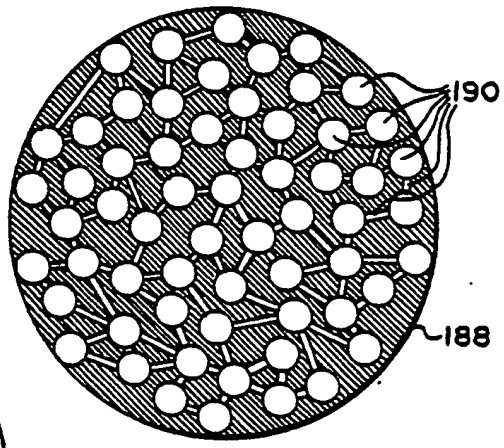


FIG. 8

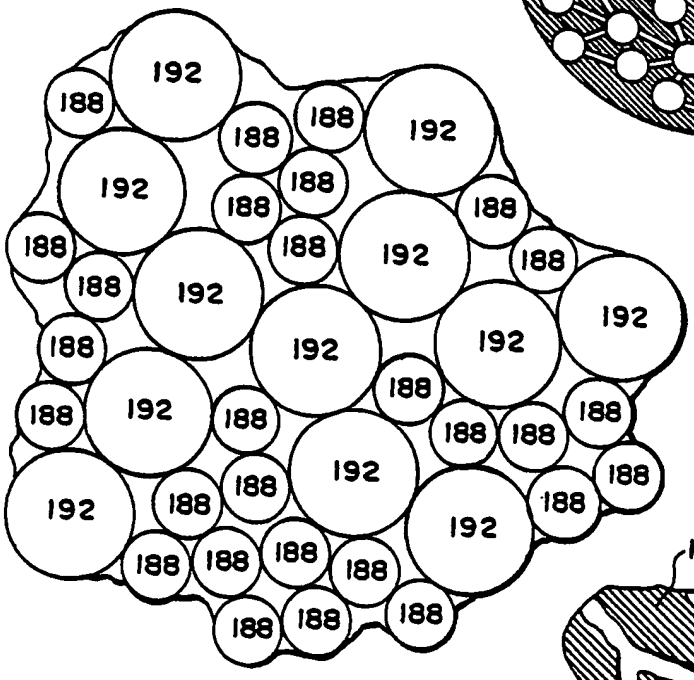


FIG. 9

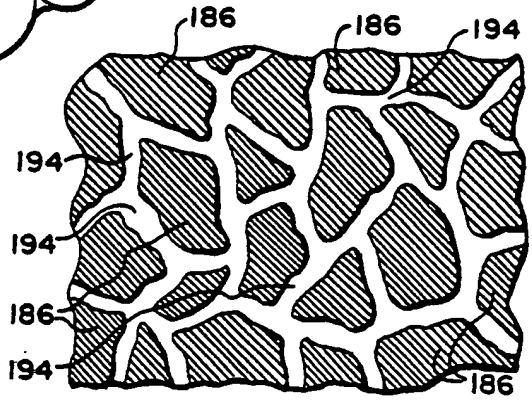


FIG. 10

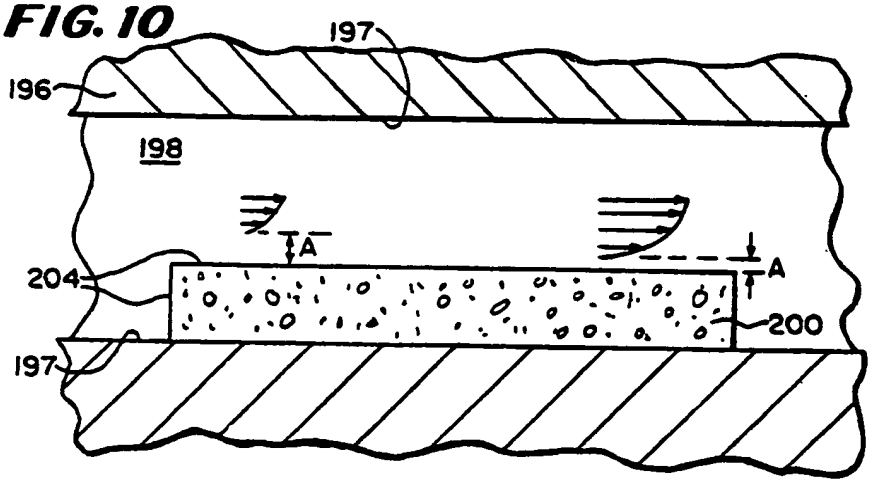


FIG. 14

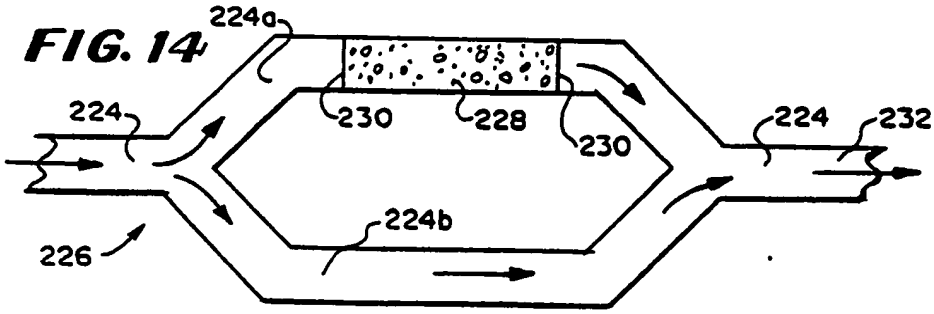


FIG. 15

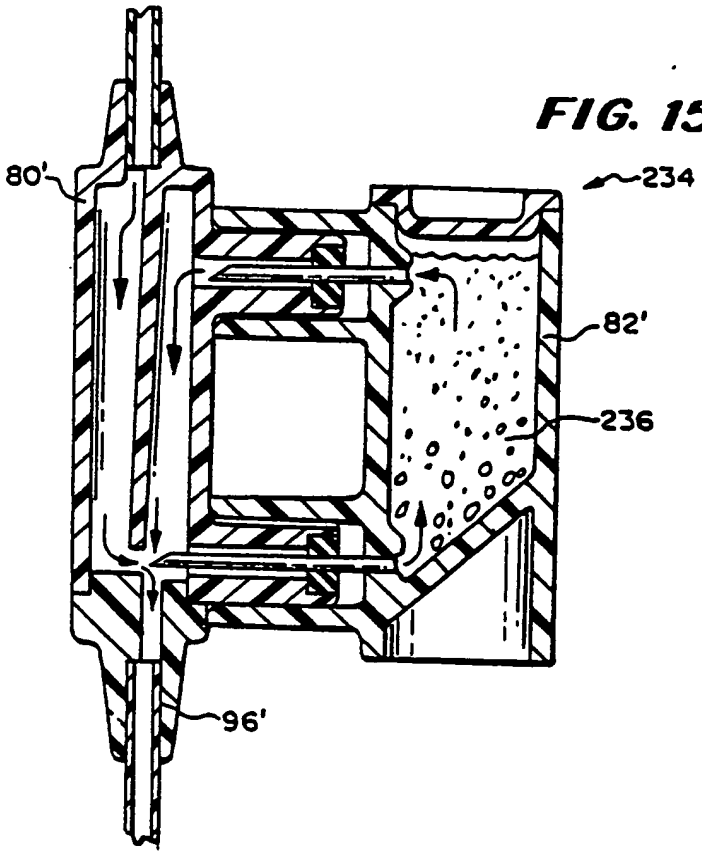


FIG. 11

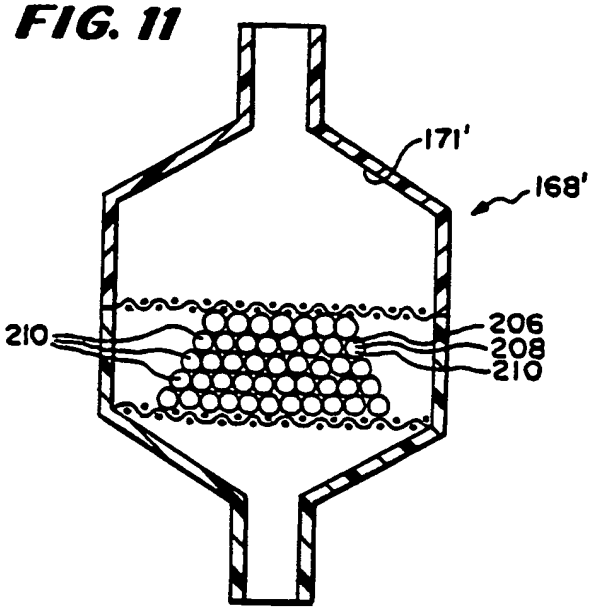


FIG. 12

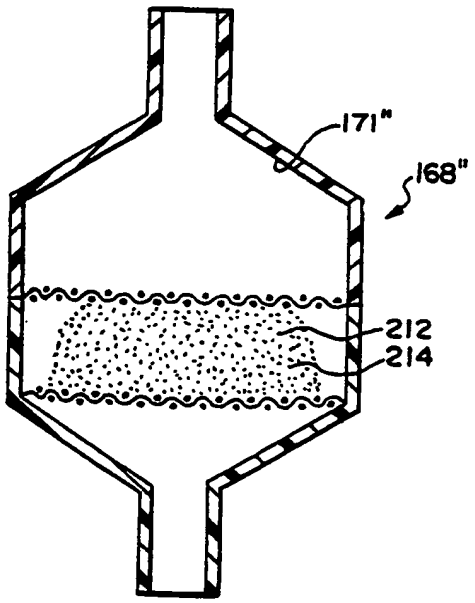


FIG. 13

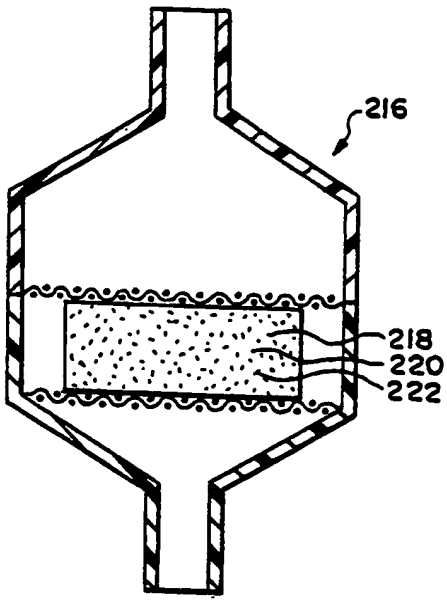


FIG. 16

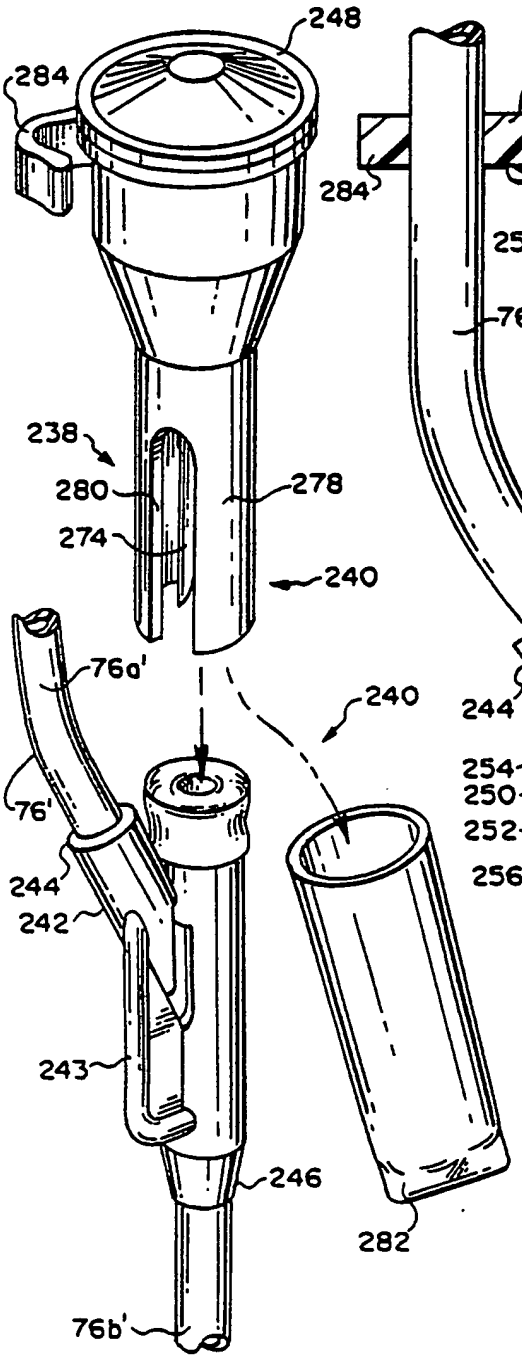

248
284
284
238
280
278
274
240
76a'
240
76'
244
242
243
246
282
76b'

FIG. 17

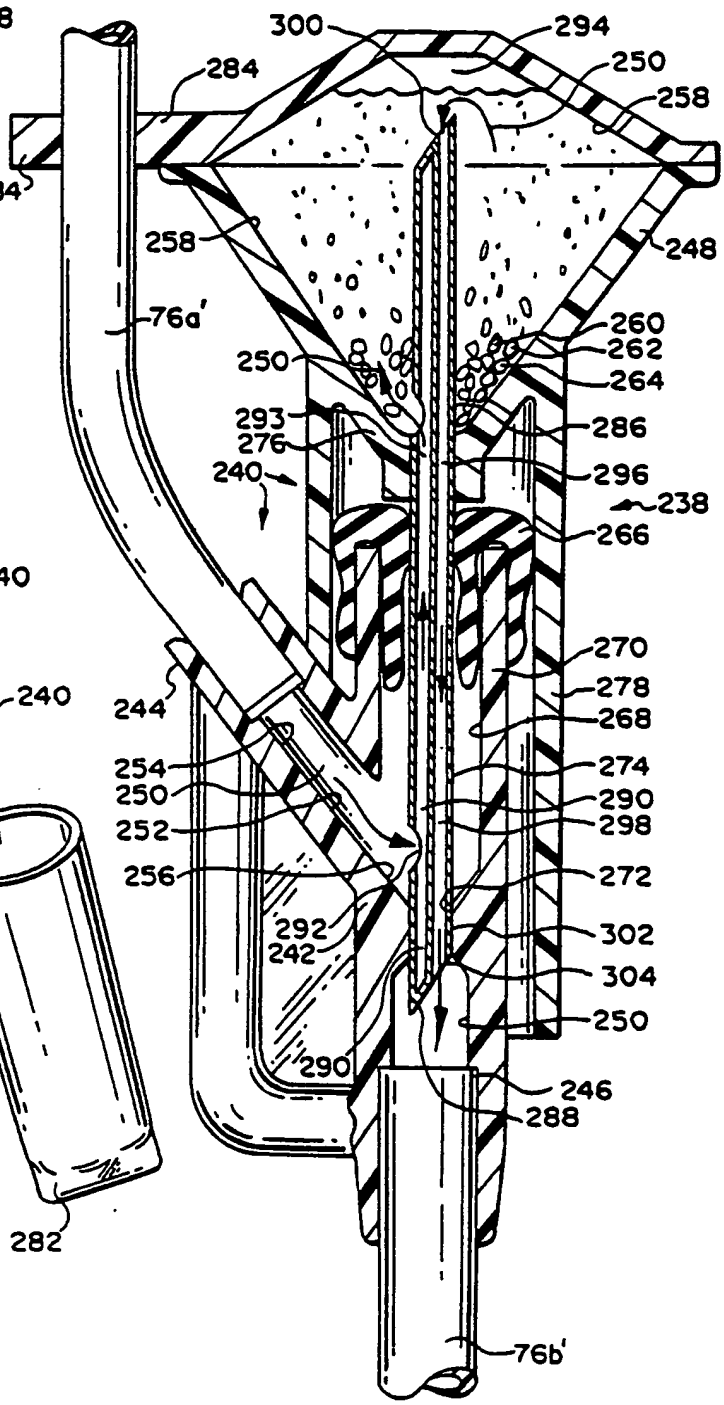

300
294
250
258
284
284
258
248
76a'
260
262
250
264
293
286
276
240
296
238
266
270
278
244
268
254
274
250
290
252
298
256
272
292
302
242
304
250
290
246
288
76b'

FIG. 18

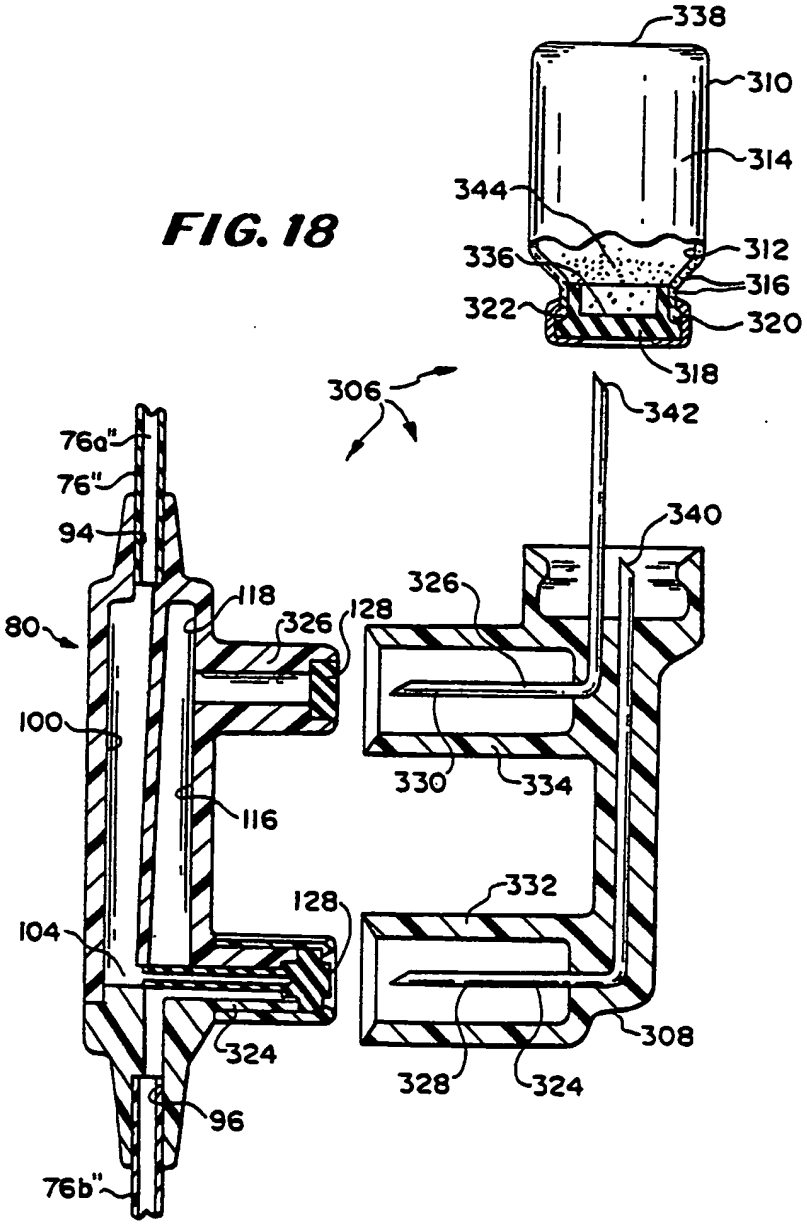
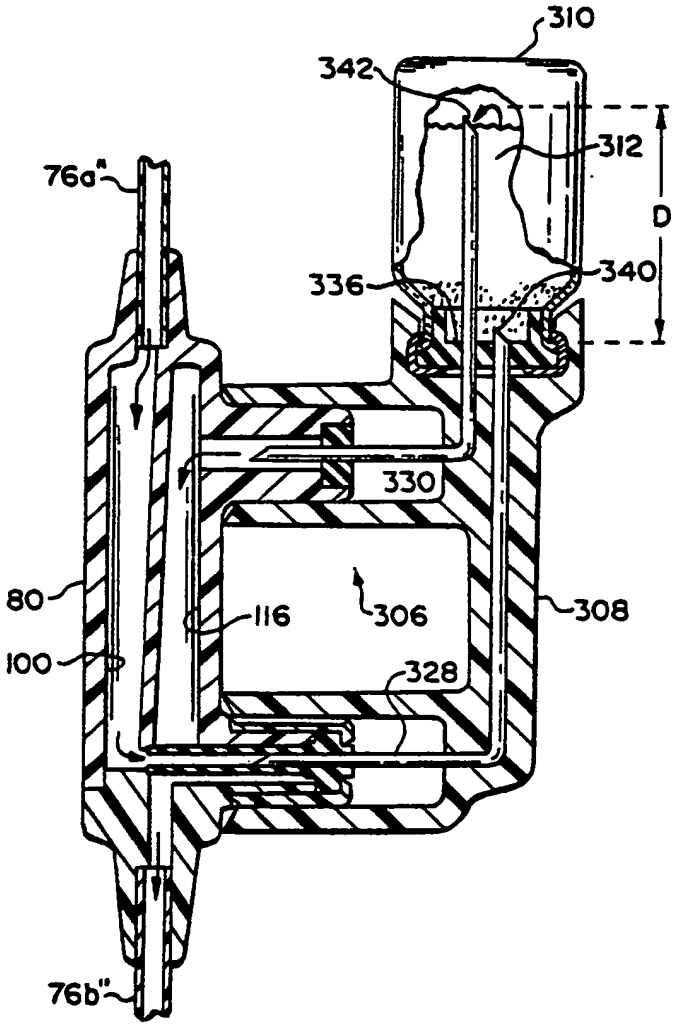

338
310
314
344
312
336
316
322
320
318
306
342
76a"
76"
94
340
326
118
326
128
80
100
330
334
116
332
128
104
308
324
328
324
96
76b"

FIG. 19



INTERNATIONAL SEARCH REPORT

International Application No PCT/US85/02356

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 3

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL 4 A61M 5/14

US. CL 604/56,85,92,406,892

II. FIELDS SEARCHED

Minimum Documentation Searched 4

Classification System	Classification Symbols
U.S.	604/56,85,92,406,892

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 5

III. DOCUMENTS CONSIDERED TO BE RELEVANT 14

Category *	Citation of Document, 16 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No. 18
Y	US, A, 4,465,471 14 August 1984 HARRIS et al	1-4,6,53,54
Y,P	US, A, 4,548,598 22 October 1985 THEEUWES	1-8,17-27, 33-37,41,42 44,47,48
Y	EP, A, 0,059,694 08 September 1982 HASSLE	1-16,37,41, 44
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Y,P	US, A, 4,511,352 16 April 1985 THEEUWES et al.	1-26,30,37 47
Y,P	US, A, 4,511,353 16 April 1985 THEEUWES	1-26,37,47 52
Y,P	US, A, 4,533,348 06 August 1985 WOLFE et al	1-4,6,17-30, 37,47,52
Y	US, A, 4,484,909 27 November 1984 URQUHART et al	1-8,27-30,33
Y	US, A, 4,093,708 06 June 1978 ZAFFARONI et al	46-48
Y	US, A, 3,923,939 02 December 1975 BAKER et	46-48
Y	US, A, 3,921,636 25 November 1975 ZAFFARONI	46-48

* Special categories of cited documents: 15

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 2	Date of Mailing of this International Search Report 2
27 January 1986	21 FEB 1986
International Searching Authority 1	Signature of Authorized Officer 20
ISA/US	J. Ferros

Form PCT/ISA/210 (second sheet) (October 1981)